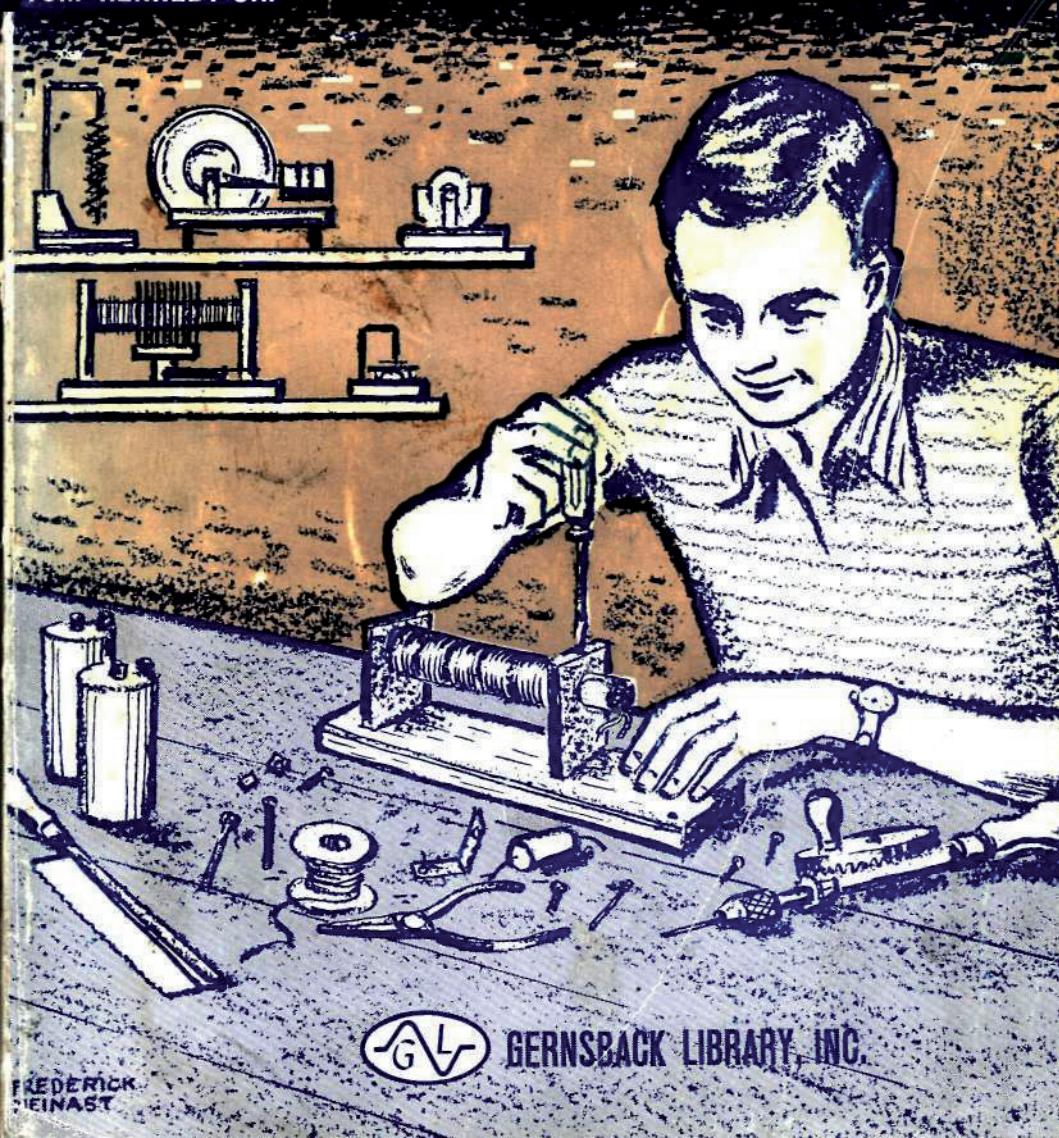


FUN WITH ELECTRICITY

TOM KENNEDY JR.

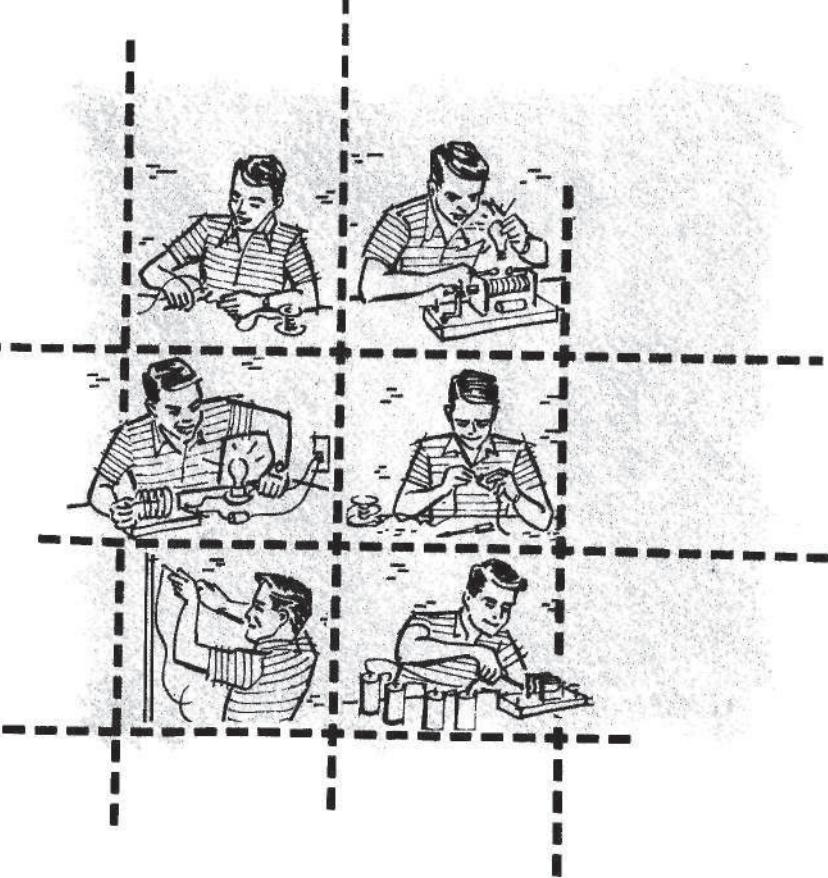


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In Memory of Edwin Howard Armstrong—believer and advocate of the practical side of education in electrical engineering—this book is dedicated.

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introduction

BUILDING and operating simple electrical apparatus in the home workshop is probably the most effective way of starting the foundation for a career in that most exciting and magical of all worlds — science. This book is a simple how-to-do-it and how-to-understand-it guide for beginners in electricity. This subject, the foundation of electronics, is the gateway to learning something of the great fundamental truths of the laws of nature.

Familiar analogies are included where possible to help fix in the mind of the experimenter the purpose of each problem and to illustrate the relationship between mechanical, electrical and magnetic phenomena. The builder not only learns to make galvanometers, motors, generators, transformers and electric meters, but also how to apply them in the solution of simple electrical problems. With this as a basis, the reader can then refer to more advanced books for an explanation of the underlying theories.

The student is guided in the handling and care of tools, and how and where to procure electrical supplies. There are many sources where materials can be purchased. These would include radio parts stores, hardware stores, department and 5- and 10-cent stores. Radio parts catalogs are excellent in this respect. And finally, with a little ingenuity, many of the items found around the home can be put to new and unexpected uses.

In this book the use of mathematics has been completely avoided. However, no study of electricity and electronics can proceed very far without some use of simple arithmetic. The reader should become familiar, as soon as possible, with the arithmetical relationships to be found in these subjects.

There is hardly a facet of life today in which some electrical device has not altered our concepts of how to do things both rapidly and well. And electronics, which is the next step beyond the scope of this book, is the modern-day magic which has extended man's senses — his sight and hearing — supplemented his brainpower, and introduced him to the mystery of galactic space. But all electronic apparatus, no matter how complex, has its roots in elementary beginnings of the type we have described. The intention in this book is to show the reader that an understanding of electricity is based on an understanding of the simple truths of electricity.

TOM KENNEDY, JR.

Technical illustrations by Frederick Neinast

CHAPTER I



electricity

ELECTRICITY has been called the *stuff* of the universe. Early scientists believed it was a kind of fluid that flowed through wires, that it was of two kinds, and that it was contained in equal amounts in neutral bodies. Now it is known as a movement of electrons — a negatively-charged body indicating an excess of electrons; a positively charged body a deficiency of electrons.

Electrons flow through wires to equalize a difference of electrical charges on two bodies (or electrical qualities), just as water flows through a pipe to equalize water pressure between two tanks. Thus, we arrive at an understanding of *electric current*, and the channel through which it flows — the *electric circuit*.

Electricity may best be regarded as an invisible conveyor of energy. Of the two kinds of electricity we know best, electricity at rest is known simply as a static charge (or more simply, *static*) that equalizes a difference of potential in the form of a spark. Electricity as a current occurs when a difference of potential is equalized more slowly, as when a current flows through a wire from one battery terminal to the other.

One of the basic things to remember is that, in an insulating material, electrons are not free to move from atom to atom, or are very few in any given quantity of the substance. In a conductor, such as copper, brass, silver or other such metals, there are many free electrons capable of being moved or pushed along under the influence of a difference of electrical potential (voltage). Thus, they are great conveyors of energy. Some materials have widely different degrees of this electronic freedom

and when they do we say they have different electrical resistances.

Thus, we have opened the door to a brief consideration of the basic elements of matter, magnetism and electricity. There is much more to the complete story, but the experimenter is asked to read the standard texts, the encyclopedias and the histories of electrical development. No more engaging reading is to be found in the whole realm of discovery than that which has come down to us through the few centuries of recorded history of electrical experimentation.

Magnetism

William Sturgeon, an English experimenter, was one of the first to build an electromagnet, a magnet created by an electric current passing through a wire wrapped around a magnetic material such as iron. Sturgeon's electromagnet was made by wrapping bare wire around an insulated core.

This was the true cradle of today's vast electrical achievements. Thus, the property of attracting iron and steel objects, and a few other materials, became known as *magnetism*, and a material that possesses it, as a *magnet*.

The natural magnet which assumes a north-south position when suspended on a string, is called a loadstone, or leading stone. Experimenters in the early days were not long in finding out that

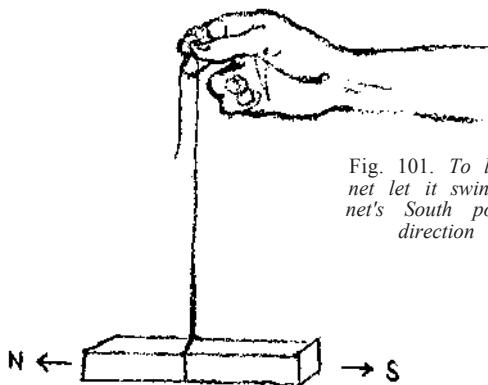


Fig. 101. To learn the polarity of a bar magnet let it swing freely on a string. The magnet's South pole will point in the general direction of the earth's North pole.

when iron or steel bars were stroked with loadstone they became magnetized, and pointed north-south when suspended at their mid-points (Fig. 101).

The force of magnetism is the real power behind the electric motor, the generator, many types of microphones, phonograph pickup heads, the doorbell, the spark coil, and the loudspeaker of

today's radios, phonographs and high-power amplifiers. Indeed, the world as we know it now could not move at all without this mysterious and all-pervading force of magnetism and its most important offspring called *magnetic induction*.

Magnetizing—what actually happens?

Looking further into magnetism, exactly what happens when iron or steel becomes partially or fully magnetized? Scientists say that molecules in the iron or steel become tiny magnets and arrange themselves in line with the magnetic field. When a piece of iron or steel is not magnetized, its molecules are scattered helter-skelter; when it is partly magnetized, a few of the molecules are arranged in line with the magnetic field, and when fully magnetized, all of the molecules are oriented so that they point from end to end in the material. In the last condition — where no further magnetization is possible — the substance is said to be magnetically saturated.

Magnetic qualities of iron and steel

A soft-iron core will not retain full magnetism when the magnetizing current in a surrounding coil of wire ceases, but certain grades or alloys of hard iron or steel such as Alnico (compounds of aluminum, nickel and cobalt) may be highly magnetized and retain this power almost indefinitely.

A permanent steel magnet can be broken into two or more pieces, with each part retaining almost its full magnetic power.

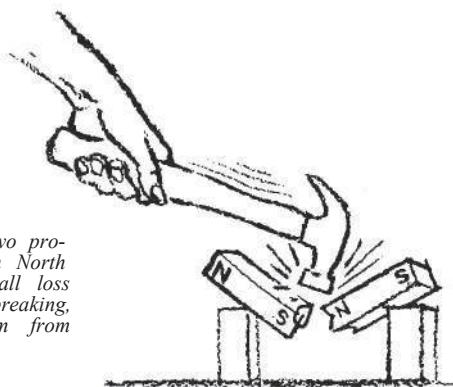


Fig. 102. Breaking a bar magnet in two produces two magnets, each with its own North and South poles. There will be a small loss of magnetic force because of this breaking, and an additional loss of magnetism from the hammer blow.

Sharp hammer blows (Fig. 102), excessive heat or application of rapidly alternating fields may partially or completely destroy the magnetic properties of a permanent magnet. But it can be magnetized again by repeating the original magnetizing process.

However, some materials cannot be magnetized and demagnetized repeatedly without losing much of their properties in the process.

About the electron

If we could divide matter into its smallest particles so that there would no longer be any possibility of physical subdivision, then we will have arrived at the status of the molecule. Divide this tiny speck of matter further and we will finally have atoms. Now if we still further subdivide matter (and this can only be done with powerful atom smashers) we will have arrived at the status of the nuclear particles, of which the electron is one.

Friction causes a lot of electrons (loosely bound electrons in and around atoms) to be *swept up* or concentrated at one spot on a conductor or insulating material for an instant, like water may be swept into the center of a floor. Such an *electronic pool* or *static charge* may be released quickly to another body which has no such concentration, and become visible as a spark. If such a charge is released more slowly through a wire, its passage constitutes an *electric current*.

Fundamental law of nucleonic forces

Unlike charges, such as an electron and its equal and oppositely charged *nucleus*, attract each other. Two electrons (negative charges) repel each other.

This is the fundamental law of nucleonic forces: unlike charges attract each other; like charges repel each other. Another way of stating this law is: minus attracts plus; two negative charges repel, and two positive charges repel.

Now let us consider the repulsive force between two spheres of electrons, each sphere weighing a gram — of which there are 28.35 in 1 ounce. If one could place these gram spheres 3/8 inch apart they would exert a repulsive force of about 320 million million million tons. A sphere of electrons and a comparable sphere of *protons*, the positive nucleonic center of the atom, would attract each other with the same tremendous force.

This nucleonic force is believed to be the extraordinary *cement of the universe* that binds all matter together. Some electrons are tightly bound to their nucleonic cores. Some are called *planetary electrons* because they rotate in fixed orbits around their cores. Some are more or less free to wander or be pushed around in the material of which they are a part.

One of the characteristics of metals is that they have large numbers of free electrons. These can be forced to travel in a wire

and thus form an electric current. In some materials there are very few electrons, and thus are poor conductors of electricity. Such materials are called *insulators*. Glass is such a material.

So great are the numbers of electrons required to weigh 1 ounce of matter that the total of these fantastically small particles would be something like 279 followed by 28 zeros. It would be interesting to just look at such a number: 2,790,000,000,000,000,000,000-000,000,000 (Fig. 103).

This number of electrons would be present in an ounce of air or an ounce of gold or silver. The only difference is that in air

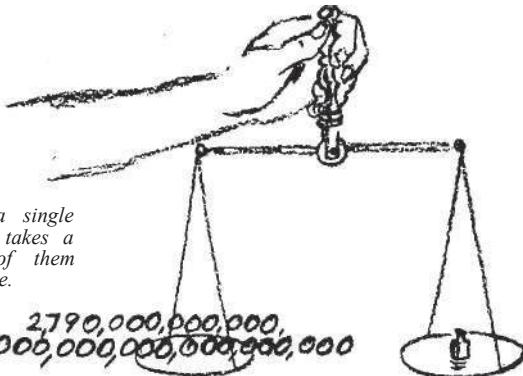


Fig. 103. *The weight of a single electron is so small that it takes a fantastically large number of them to weigh just 1 ounce.*

electrons are more widely separated from each other; in gold or silver (or some other dense metal), they are packed tightly together.

Heat results from electronic activity or agitation that causes electrons to bump or rub together, which raises the temperature. All materials have a certain degree of this nucleonic activity, in direct relation to their respective normal temperatures. Red-hot metals, obviously, are in a state of high agitation; frozen metals are in a very low state of nucleonic agitation. Strike a steel bar with a hammer and its temperature is appreciably raised. Agitation of its nucleonic particles is what causes it.

Specialists who study infra-red rays say that everything on earth emits infra-red energy which can be *seen* with the aid of infra-red detector crystals. Such emission of energy ceases only when matter is reduced in temperature to near the absolute-zero mark, or 459.6 degrees below zero Fahrenheit.

This is but a little of the mysterious world of matter of which we and everything else are a part.

No two molecules of matter, we are told by specialists in this

field of research, are in permanent contact with each other, and only at absolute zero are they really quiet. Thus, all matter is in a continual dance or vibration, which increases in vigor as the temperatures rises and they push farther apart from each other. This accounts for a metal's gradual physical expansion as temperature rises.

What is the chief difference between an atom and a molecule? Perhaps the classic explanation is that an atom is a chemist's unit of matter, whereas a molecule is the physicist's. The meaning is that in an ordinary physical change — evaporation, heating, cooling, contraction or expansion — a molecule's physical constitution is not altered. In such phenomena, changes are only in the position and relation of one molecule with another.

However, when a chemical change occurs, the molecules are broken up into their constituent atoms and entirely new molecules are formed. For example, if sugar and sand are mixed, the mixture is only physical and it is possible to separate one from the



Fig. 104. Rubbing glass with silk removes electrons, causing a shortage, or a positive charge on the glass.

other. But if coal and oxygen are brought together as in a fire, the physical properties of each are lost and new substances are formed — smoke and ashes. This is a chemical change, because old molecules are modified and new ones formed.

This, in part, explains something about the three states of matter: solid, liquid and gaseous. When ordinary substances become very hot they melt, and as they become still hotter they evaporate. But no subdivision of the atom happens. This can be done only by more drastic means, such as nuclear bombardment in machines that fire nuclear bullets and thus disassociate electrons from their nuclear cores, and even break up the cores themselves.

But why, if electrons and their nuclear centers are so tightly cemented together, may one rub a material such as dry glass with

silk (Fig. 104) and generate an electric charge? Remember that any material has a relatively large number of wandering or free electrons, not enough to carry an electric current, but enough to be rubbed off by main force of heavy friction and accumulated into a pool which is virtually kicked off the substance by the enormous repulsion of electrons with each other. This wonderful effect one may observe and feel with simple apparatus built in the home workshop.

Tools and techniques

Something about electricity fascinates all of us. Perhaps it is the mystery of silent power feeding gigantic machines, or the warm glow of the lamp in our living room or a silent electric stove. The power behind our everyday appliances has something universal about it which embraces all modern technology. If you have ever watched an electrician at work, the variety of tools he

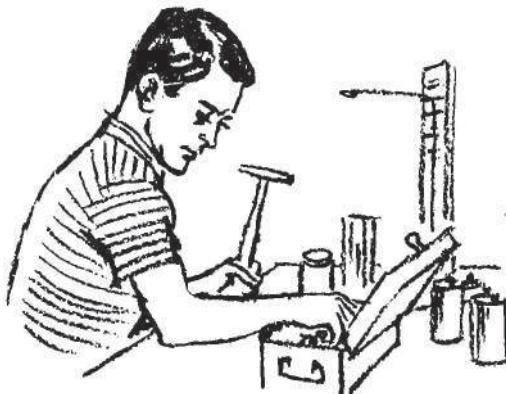


Fig. 105. Your home toolbox will probably contain most of the tools needed for experiments in electricity.

carries will amaze you. From screwdriver to woodsaw, he comes armed to meet any requirement placed upon him. However, to have *fun* with electricity you don't have to be a walking tool shop. The projects in this book require a minimum number of tools all of which can be found in a hardware store or home toolbox (Fig. 105). None of them are difficult to use, but it is a good idea to get acquainted with them so that building the models will be an easy and enjoyable task.

The projects in this book start simply and work up to fairly complex electrical instruments. If this is your first try at building electrical models, start at the very beginning and work up to the

complicated jobs. But whether or not you have had experience, take the time to read about the tools you are going to use. Many times a model will not work because it was built in haste by someone who assumed that he knew how to *use* tools when he only knew what they were supposed to do.

Tools in the hands of skilled workmen have built the modern world. The hammer, saw, knife, axe, chisel and drill are the rungs of the ladder which man has used to climb from a humble hunter to the cosmopolitan he is today.

A good craftsman and his tools form an inseparable unit. Next time you watch a master carpenter at work note the skill with which he drives a nail or cuts a board. Listen to the sharp ping as the hammer strikes squarely on the head of a large nail or spike, or the crisp sound of a sharp saw as timber is cut. If you look closely you'll see that the experienced craftsman never forces a tool, but with seeming ease drives a spike with a few ringing blows of a hammer. The saw he wields melts through a board effortlessly as man and tool combine into a graceful effort-saving unit.

All of these things are the trademark of skill acquired after much practice with tools in tip-top condition. But dexterity can be developed by anyone with ordinary coordination, and anyone can learn to keep tools in good condition. When one understands his tools and their limitations and becomes skilled in their use, they become extensions of the hand holding them. One instinctively applies them to the task with an air of authority, the mark of a craftsman.

Use and care of tools

Since the projects in this book are made from wood and metal, you will need an assortment of tools suitable for use with these materials. Few tools are made to be used with both; nevertheless the basic tools you will need are not as numerous as would seem. Most of them can be found in even the skimpiest family toolbox, the others are inexpensive and easy to obtain.

The wood saw

An essential tool in any toolbox, the wood saw must be selected carefully and treated with respect. A 2-foot crosscut saw with relatively fine teeth is one of the most useful. Not too large to be unwieldy, but large enough to tackle almost anything from the small piece of wood you will be using to most of the larger sizes used for construction.

Respect the wood saw by keeping it clean and dry. Coat it from time to time with machine oil to prevent rust (Fig. 106). When using the saw, never force it into the cut. Let the saw do the work by

Fig. 106. *Treat the wood saw with respect by keeping it clean and dry. To prevent rust, coat it every so often with a fine machine oil.*



using long relaxed strokes. If the saw binds do not apply pressure to it; you can permanently warp or even snap the blade. Binding is a sign of dullness, or may mean that the teeth have lost their set. If you have a saw with this symptom let a professional sharpen it for you. One of the most common causes of a ruined saw is using it to cut through nails buried in wood, or laying it down on a cluttered bench where metal objects can hit the cutting edge. Always hang up a saw after use to protect it, and remove all nails from scrapwood before beginning a cut.

The hacksaw

Another tool found in most toolboxes is the hacksaw. An ideal tool for general metal work, hacksaws come in a variety of sizes and shapes. The most familiar consists of a frame of adjustable length to which various blades can be attached. A good hacksaw with a variety of blades can be fairly costly. If you do not already have one and wish to economize, a small pistol-grip keyhole saw can be used instead. Not as elaborate as a hacksaw, it is nevertheless easy to use. Because the blade is supported at only one end, it is heavier than those used in a hacksaw. However, saws of this kind can be used for making long cuts in heavy sheet metal—a hacksaw usually cannot.

The vise

For holding metal parts being cut, drilled or bent, a small bench vise is needed. If you are looking for a quality tool which will have a long life, a forged-steel unit is best. A small cast-iron vise, though, is inexpensive and will do the job. A vise with 1-2-

inch jaws will be large enough for your needs. Get the kind which can be clamped to a table edge; it is handy and portable. Most units are predrilled for permanent installation too.

In general, vises are sturdy tools which need little care. However, when cutting metal, always end the cut so that you do not cut into and damage the vise. To protect fragile or soft metal parts from the hard jaws of the vise, clamp the part between wood

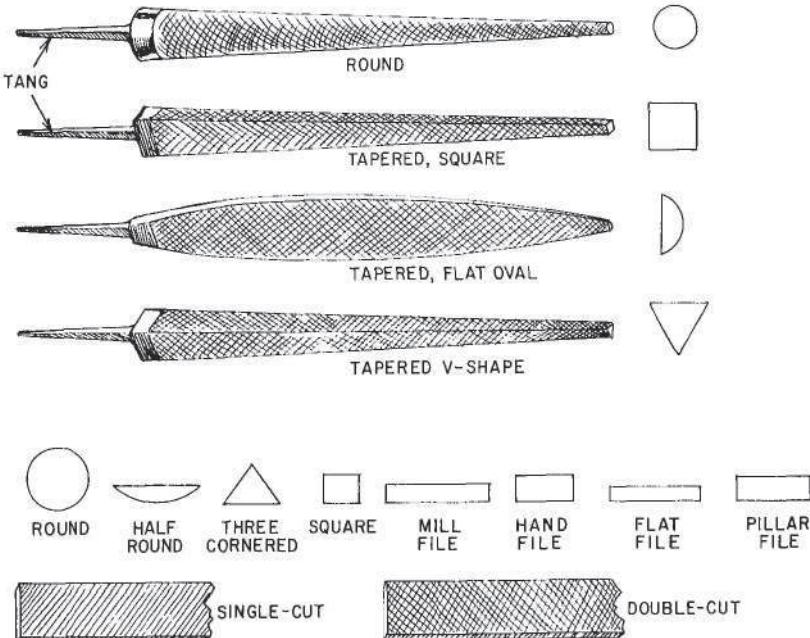


Fig. 107. For your basic tool kit, choose a well-rounded assortment of files—small, medium and large sizes, fine and coarse, flat, round and half-round.

blocks or line the jaws with sheet aluminum or other soft metal. Although many vises are built with a section that looks like a miniature anvil, do not use this surface for hammering metal parts. The materials used to manufacture vises are designed to withstand pressure, not sharp blows. You can easily crack or otherwise damage a vise by using it as a hammering surface.

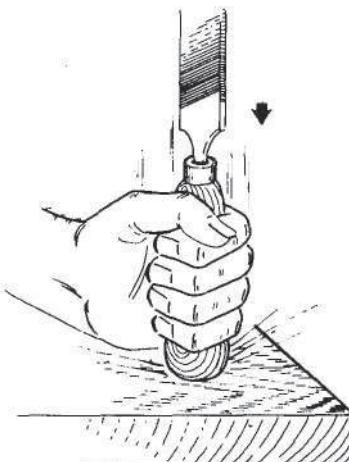
Files

A set of files—large, medium and small sizes, coarse and fine, flat, round and half-round—is an important part of any basic tool kit (Fig. 107). Whether the particular file you use is a fine-toothed unit for finishing metal or a coarse wood rasp, never use it without a handle. The tapered tang which is exposed can easily

puncture the palm of the hand. For the sake of economy, two or three handles of assorted sizes can be used with a large combination of various sizes and types of files. The handles are easily removed and fitted to the tangs (Fig. 108) and it is a simple procedure to transfer them from one file to another.

Clean your files with a stiff wire brush and store them in a dry place—a rusty file is a ruined one. When you use a file, grasp it by the handle and tip and do not apply too much pressure.

Fig. 108. *Whichever file you prefer, always use it with a handle. It's easy to remove and transfer handles from one file to another.*



Because they have to be extremely hard, files are not very flexible. The metal is brittle and excess pressure on both ends of a file will eventually make it snap. The correct way to use a file is shown in Fig. 109.

The drill

A small hand drill of the eggbeater type is another necessary tool. Its chuck must be large enough to accept at least a $\frac{1}{4}$ -inch bit. Keep the gears of the drill well oiled, and remember to lubricate the chuck to prevent binding.

There is a trick to using a drill properly; it is simply a matter of keeping the bits sharp. Never be in a hurry to finish a hole. Spinning the drill fast and applying pressure is a good way to draw the temper of the bit and ruin it.

When you have to drill metal, use a prick punch or an icepick to help get the drill started. Nick the metal with the punch. The small indentation helps the drill bite into the work and get started. Again, let the drill do the work. When bits are in good

condition and the drill well oiled, you will never have to use much pressure to finish a hole quickly and easily.

Pliers

There are as many sizes and shapes of pliers as there are people who use them. Pliers are used for holding and gripping and are

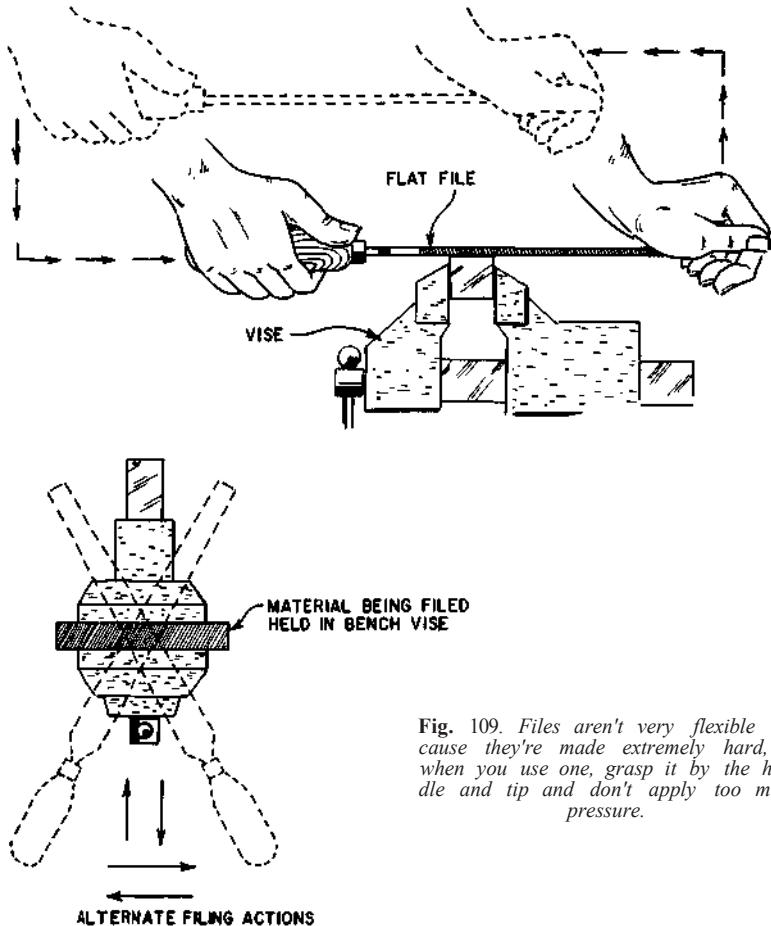


Fig. 109. Files aren't very flexible because they're made extremely hard, so when you use one, grasp it by the handle and tip and don't apply too much pressure.

usually designed with a specific purpose in mind. For electrical work one of the most useful tools is a 6-inch pair of flat or chain-nose pliers with side cutters. You can use them to hold small parts, shape sheet metal and cut and strip wire. For cutting off the ends of small bolts or trimming wire in close quarters diagonal cutters are useful. A must for electrical work, they are specifically designed for it.

Screwdrivers

Perhaps the most important—at least the most often used—tool is the screwdriver. Designed to drive and loosen screws—not for chopping holes in cement or opening tin cans—this specialized tool is often abused by improper use and care.

The tip of a screwdriver must be kept square and its edges sharp to provide a good grip in the slot of a screw. Any use which will dull the edges of the blade or tend to wear it out of square is an improper one and must be avoided.

There is one peculiarity of this tool which seems to be common to no other: it is impossible ever to have a large enough assortment of screwdrivers. Though they range in size from the jeweler's minute instrument to units with a 2-foot shaft and a blade almost 1 inch across, there still doesn't seem to be enough of them. However, an inexpensive one about 6 inches long and with a plastic handle will be adequate for most jobs.

Aside from a folding knife and a ruler, you will not need any other major wood- or metal-working tools. There is one item, however, without which you will be unable to do any electrical work. A highly specialized tool, its use and care deserve special attention.

The soldering iron

Soldering remains to this day the ideal way of making electrical connections. Good soldering is an art.

The ideal tool for the kind of work you will be doing is a 75-100-watt soldering iron. If you purchase a new one, the chances are that the tip will be already tinned. However, not all manufacturers pre-tin their products. If you already have a soldering iron, prior usage will probably have destroyed the tinning.

To produce electrically sound joints, the iron must be clean and well tinned (Fig. 110). The tinning process is a simple one and can be accomplished in a matter of minutes. First plug in the iron and allow it to get hot. Gently file the tip until the bare metal shows. Clean each face of the tip separately. As you finish cleaning each section, melt a little rosin-core solder onto it. Gradually build up a rather heavy coating on the tip of the iron. When all the faces of the tip are coated, rub it with a piece of cloth until it takes on a bright silver sheen.

To maintain the tinned surface, wipe the iron with a cloth whenever it is used. The solder it picks up as you use it will constantly re-tin the tip, provided you wipe off the dross and oxides formed on the surface during normal soldering.

Making a soldered joint

There is really no mystery involved in making good soldering joints; all you need is a well tinned iron, the proper solder and a clean, mechanically secure joint.

Solder comes in a variety of sizes, shapes and types. For electrical work, wire solder of the rosin-core type is the only kind that should be used. The flux is contained in the solder and is fed to the work automatically.

The first step is to clean the ends of the wires of all insulation. Much of the wire used in the projects in this book is insulated with baked enamel. You cannot solder through enamel so it must be removed. Scrape the enamel from the wire with a knife or piece

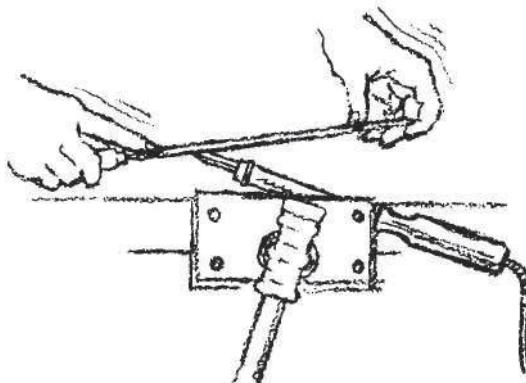


Fig. 110. *To get good electrically sound joints, keep the iron clean and well tinned. Once you have it properly tinned, wipe the tip with a cloth whenever you use the iron.*

of sandpaper. Make sure that the bare metal is exposed. Twist the ends of the wires to be soldered firmly together and then apply heat to the joint with the soldering iron. Touch the solder to the joint until the solder melts and flows smoothly into the joint. Then remove the iron and the solder and allow the joint to cool. To give the solder a chance to set properly, do not move the joint during the cooling process.

Fig. 111 shows how the solder is applied to the joint. Notice that it is the heated joint which melts the solder. Do not melt the solder on the iron and carry it to the work. Also do not apply the solder to the tip of the iron and let it flow onto the work. If you do any of these things, the resulting joint will be one that cannot be trusted.

Because of the variety of solders that can be obtained, it is a good idea to stick to the type used almost exclusively in electrical and radio work. Get a good grade of rosin-core solder, one that melts and flows easily. The melting temperature of solder is determined by the mixture of tin and lead. A 60/40 type has a low melting point and flows easily.

A place to work

When you get down to basics, all that you need in the way of a workbench is an old card table. Placed near electrical outlets and supplied with a source of light, it is a working surface spacious enough and well suited for the kind of work you will be doing.

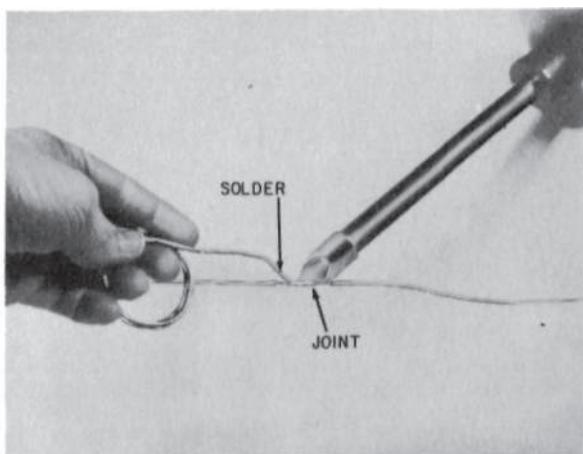


Fig. 111. With one hand, hold the soldering iron next to the joint; with the other, hold the solder to the joint. When the joint gets hot enough, the solder will melt and flow smoothly around it.

Although the card table will do the job, ideally a sturdier surface should be used. An old kitchen table, with strong legs makes a good workbench. The drawer is a handy place to store small parts and tools, and you can clamp a vise onto the edge of the table.

The workbench illustrated in Fig. 112 is a table which has been tailored to meet an electrical hobbyist's needs. You will not require—though you would enjoy—something as elaborate as this. As long as there are nearby wall outlets, you do not have to wire the bench, nor is it necessary to build a tool rack.

Because the surface of the bench is wood, cover at least a portion of it with a piece of sheet metal or, better yet, a square

of asbestos. Asbestos siding is easily obtained and will guard the bench from accidental swipes with a hot soldering iron.

Lighting is one of the more important factors which must be considered when you have decided upon the spot in which you are to work. Ideally you should work near a window, as shown in Fig. 112. However, if you are going to do most of your work at night or cannot place the bench near a window, lighting can

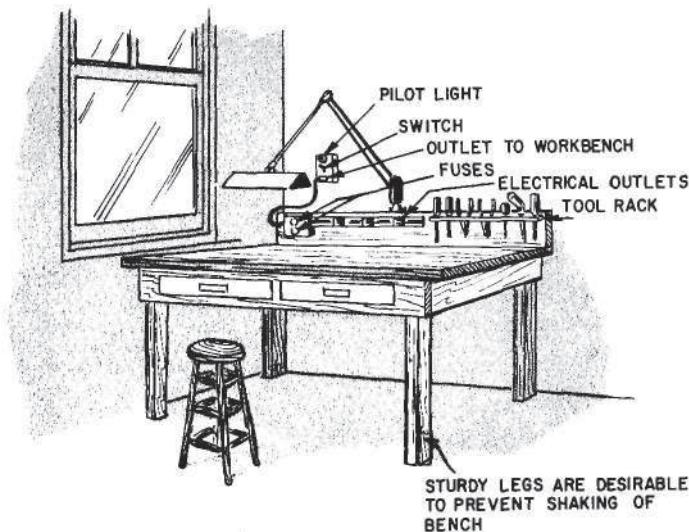


Fig. 112. This table has been converted into a workbench and tailored to meet an electrical hobbyist's needs. Notice how the bench has been placed near a window for adequate lighting.

be a problem. Never rely on ceiling lights; they usually are not in the right place. Even if a ceiling lamp is over the bench, the chances are that it will not throw enough light to prevent fatigue. Use a gooseneck desk lamp (or the type shown in Fig. 112) so that you can adjust the light to fall on whatever you're working on. If you do not have a desk lamp, use a floor lamp placed behind your left shoulder. The bulb should be at least 100 watts so that the work is powerfully illuminated.

Safety

In this first chapter we have been stressing the use and care of tools. Personal safety is even more important. The proper use of tools is, of course, the first step to safety. But tools can slip, slide or drop, and may hurt you in the process.

We cannot set up a list of safety rules guaranteeing that no

accident will ever happen. Freak accidents do occur. But you can increase your own safety through the application of some common-sense precautions.

The head of a hammer must be absolutely secure and fixed in place. If the head is loose, don't use the hammer. Hardware stores sell metal wedges which can be driven into the hammer to fasten the head into position. If the hammer handle is wood, make sure it isn't splintered or split. If it is, don't use it. Splinters are painful.

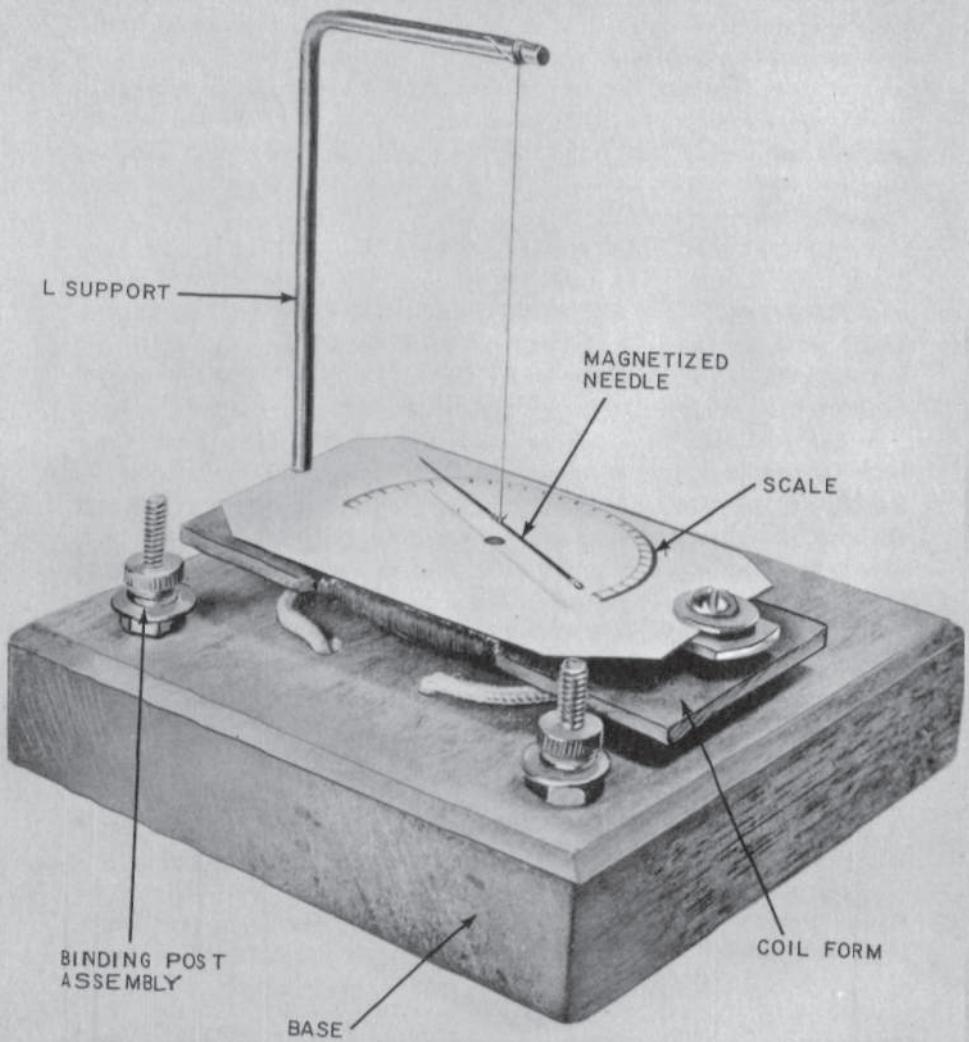
Saws can cut fingers as easily as they cut wood. Some saws, such as hacksaws, require the use of two hands, so you have a built-in safety precaution. But other saws, such as wood saws, are usually worked with only one hand. If you must use your free hand to support work which is being sawed, keep your hand well away from the moving teeth of the saw.

You might think that a vise, fastened as it is to a bench, isn't dangerous. Large vises have heavy handles. Since these handles slide easily, they have a habit of waiting for unsuspecting fingers. Don't let it be yours. Look out for jagged pieces of scrap remaining between the jaws. Keep the vise clean. Remember also that a vise can exert tremendous pressure so keep your fingers out of the way.

When you use a file, make sure it has a handle. The danger here is that handles have a habit of slipping off and rolling under the bench, out of reach. There will be a temptation to use the file without the handle. Don't do it! Don't ever try to use a file as a hammer or lever. Files are brittle and when they snap they are dangerous.

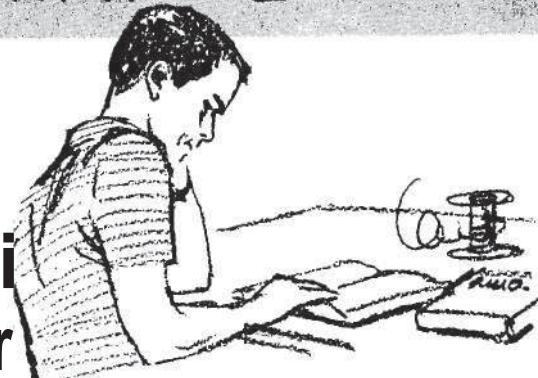
Do not wear a necktie when drilling (particularly an electric drill). The same precaution applies if you have any motor-powered tools. Some motor tools are geared down and have tremendous torque (turning power). Some motors have open frame construction. Poking inside them when they are connected will damage both motor and you.

The second rule of good soldering is cleanliness. The first is safety. Don't vibrate or shake the iron to get rid of excess solder. Hot solder can cause a severe burn. Use a good soldering iron stand, preferably one that is enclosed on all sides. This will help avoid the possibility of touching the hot iron accidentally.



CHAPTER 2

the galvanometer



ONE of the first instruments used to measure and demonstrate the presence of electric current, the magnetic-needle galvanometer derives its name from that of Luigi Galvani, an early experimenter. At one time an electric current was commonly called a galvanic current in honor of this pioneer in physical science. It followed that an instrument used to measure or indicate electricity would be called a galvanometer.

We take the movements of electric currents so much for granted that it is hard to believe there was a time when we did not have electricity available to do all the work we demand. Before we could use electricity, we had to have some way of measuring it and knowing where, and when, and how it moved. Since electricity is invisible, one of the first steps toward learning more about it was the construction of suitable instruments that would help us keep an "eye" on the flow of electric currents.

Basically, all electric measuring instruments are very simple. They can be constructed in a very elementary manner, such as the galvanometer we are going to build in this chapter, or as more refined and professional looking instruments, such as those we will build in chapter 10. Before you start construction, though, read the chapter very carefully and make sure you understand the detailed instructions.

How it works

The importance of understanding how a galvanometer works can hardly be overestimated, for the magnetic principle involved

Fig. 201. *The magnetic principle of the galvanometer is applied in almost all electrical apparatus.*

is applied in nearly all electrical apparatus, from the simplest device to the world's largest motors and generators.

Although it has been refined and changed through the years, this basic tool remains one of the standbys of modern designers and engineers. There are many types of galvanometers, but almost all of them are based on simple principles discovered early in the history of the science of electricity.

Many years ago it was learned that magnetism and electricity have a profound effect on each other. Electricity can be used to generate magnetism, and magnetism can generate electricity. In fact, a small magnet, such as the needle in a compass, will move when a wire carrying an electric current is placed near it. This is because the current in the wire produces a magnetic field. If the North pole of the field corresponds with the South pole of the magnet, it will be attracted. If the current produces a field so that two like poles come near each other, the magnet will be repulsed.

Fig. 201 illustrates an easily built galvanometer which uses the magnetized-needle principle. Instead of a single wire, a coil is used to concentrate the magnetic field produced by current moving through it.

The magnetized needle of your terrestrial-compass type of galvanometer, when at rest on the workbench with all iron, steel or other magnets removed to safe distances (8 to 10 feet), accurately indicates the direction of the earth's magnetic lines of force at your location — the North-seeking end of the needle pointer facing toward the North magnetic pole, etc.

However, when a wire carrying direct current from a battery or other source is brought near the needle, it becomes agitated and moves to one side or the other. A permanent magnet will do the same thing. Obviously, the current-carrying wire, like a permanent magnet, also generates magnetism; hence it has an enveloping *field* of magnetic lines of force surrounding the conductor in a clockwise direction when the electric current is traveling away from you in the wire, and counterclockwise when the current direction in the wire is reversed.

Combinations of wires, as in a coil, follow the same general magnetic law when all the turns are wound in the same direction, as in our galvanometer.

One of the laws of magnetism is that all magnetic lines of force like to travel in parallel lines in the same direction, like a current of water in a river. This is what makes the magnetized needle

point northward. In this position, its own lines of force and those of the earth are more or less parallel and both are traveling north, with the least amount of opposition between them.

Scientists compare the phenomenon to that of a ribbon tied to the front cage of an electric fan. When the fan is turned on, the ribbon is carried outward in precisely the same way the air is blown and parallel to it.

Obviously, when a wire carrying a direct current or a permanent magnet is brought near the needle, it exerts a more powerful magnetic attraction or repulsion than the earth's magnetism and the galvanometer needle swings one way or the other, depending upon the balance of magnetic forces.

Building procedure

Before you begin to construct the galvanometer, study Figs. 201 and 202. Fig. 201 is a photograph of the completed unit; Fig. 202 is an exploded view. Do not be fooled by the seeming complexity of Fig. 202. When you get used to looking at exploded views, you will find that it is possible to build a complete working model from one of them. Essentially, an exploded view is a three-dimensional blueprint. Not only does it show you the size of each part, but it also explains how the parts are put together.

Although an experienced worker can use the exploded view as his sole working guide, several other illustrations, are provided to help you. Although you may not have to use all of them, it is a good idea to examine them carefully, so that you get a good idea of just how easily the unit can be built. Throughout the text we will refer to the various simplified illustrations; however, if you desire, you can overlook these references and use the exploded view instead.

Begin building the galvanometer by preparing the base. Cut a piece of $\frac{3}{4}$ -inch scrap wood into a $3\frac{3}{4}$ -inch square (Fig. 203). Bore two $\frac{1}{8}$ -inch holes completely through the base and counter-sink each hole with a $\frac{3}{8}$ or $\frac{1}{4}$ -inch bit. These will be used to mount binding posts for connecting external sources of electric current to the galvanometer.

The next step is to cut out the form for the coil. Prepare a piece of fiberboard (Masonite) $3\frac{1}{4}$ inches long, $1\frac{1}{2}$ inches wide and $\frac{1}{8}$ inch thick. Use a file to make notches 1 inch wide and $\frac{1}{4}$ inch deep in the sides of the coil form, as shown in Fig. 204. Drill two $\frac{1}{16}$ -inch holes on each side of one of the slots as shown. Finally, drill a $\frac{1}{8}$ -inch hole $\frac{1}{4}$ inch from each end of the coil form. Center the coil form over the base and mark the position of

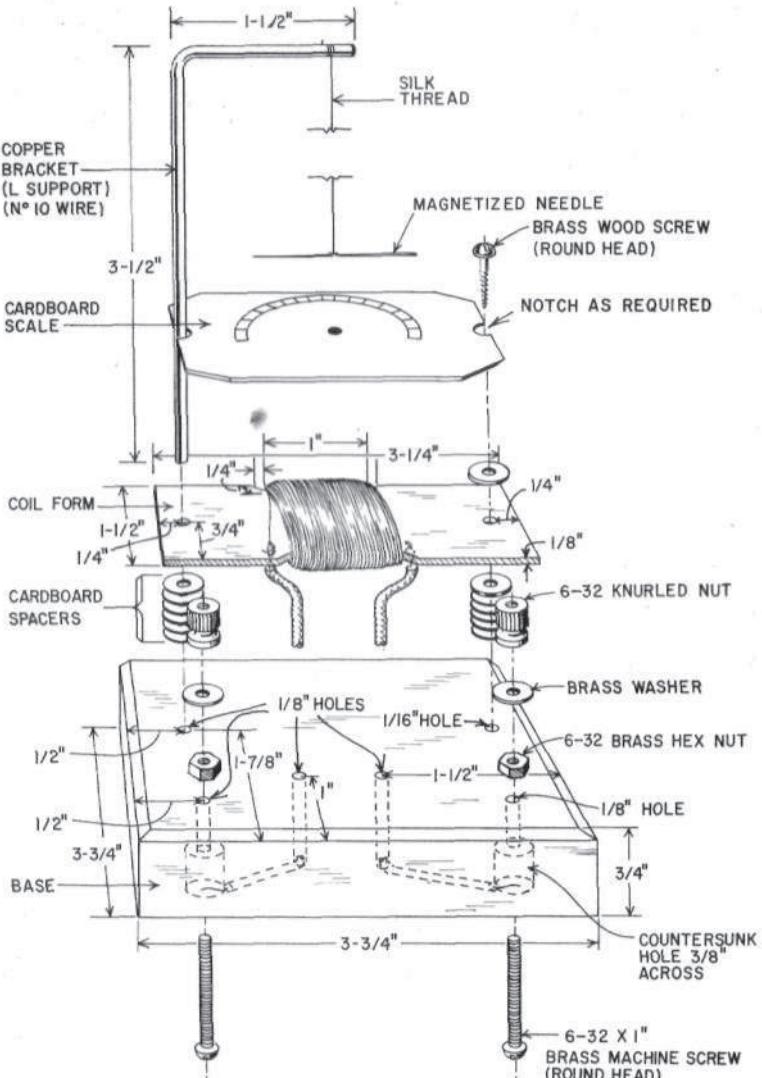


Fig. 202. Exploded view of the galvanometer. It's possible, with a little experience, to build a complete working model from this illustration.

parts list for galvanometer

Wire: 100 feet No. 28 enameled; 6 inches No. 10, enameled or bare; 8 inches No. 20 pushback.
 Hardware: 2—1-inch 6-32 roundhead brass machine screws; 2—6-32 brass nuts; 2—brass washers; 2— $\frac{3}{4}$ -inch roundhead brass woodscrews; 2—6-32 knurled nuts.
 Miscellaneous: Scrap wood for base; Masonite ($3\frac{1}{4} \times 1\frac{1}{2} \times 1/8$ inch); 1—2-inch steel sewing needle; silk thread; stiff white paper or cardboard; Duco cement; solder; cardboard spacers.

the mounting holes drilled in the form with a sharp pencil or punch. Drill a 1/16-inch hole halfway through the base on the right side and a 1/8-inch hole on the left. The positions of these holes, which are used to mount the coil form and the L support, are shown in Fig. 203.

Put the base aside for a time while you prepare the coil.

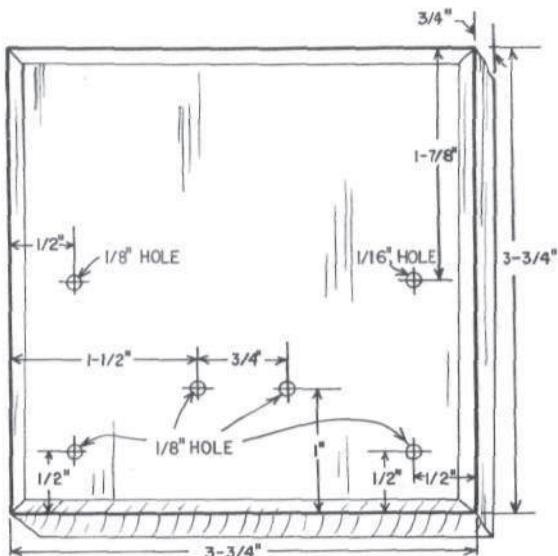


Fig. 203. First step in building the galvanometer—preparing the base. A $\frac{3}{4}$ -inch thick piece of scrap wood is cut into a $3\frac{3}{4}$ -inch square.

The coil consists of 100 feet of No. 28 enameled wire wound on the form. Hold the form in your left hand, placing the wire (about 3 inches from the end of the wire) under your left thumb. Then wind the wire evenly around the form until the slots are full. You should end up with several inches of wire hanging over at each end of the coil.

Put Duco cement at the corners of the slots to hold the finished coil in place. After the cement is dry, scrape the insulation from the loose ends of the coil. Make sure the bare copper is exposed. Thread the beginning of one wire through the 1/16-inch holes drilled on one side of the slot (Fig. 205). Do the same with the other wire, using the holes on the opposite side of the slot.

Cut two 4-inch pieces of heavier wire (No. 20 pushback wire is ideal) and remove the insulation from both ends of the wire. Insert one end of each of these wires in the 1/16-inch holes, one wire going to each side of the coil. Carefully solder the wires to

the ends of the coil already threaded through the holes. After you have made the connection, attach one of the wires to a battery. Brush the other wire against the opposite terminal of the battery. As you make and break the contact, you should see a

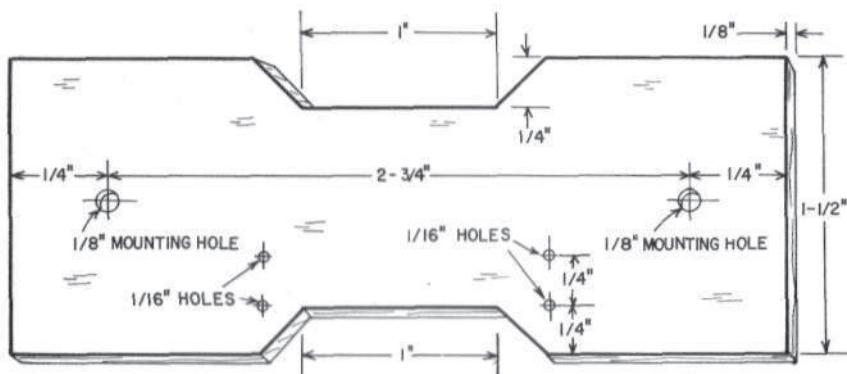


Fig. 204. The coil form is cut from a piece of fiberboard (Masonite) $3\frac{3}{4}$ inches long, $1\frac{1}{2}$ inches wide and $\frac{1}{8}$ inch thick.

small spark. If you do not, check the soldered connections. If necessary, resolder the joints by reheating them and applying a little fresh solder.

When you are satisfied that the coil is functioning, lay it aside

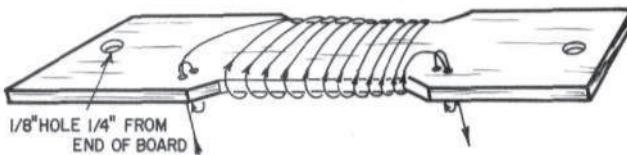


Fig. 205. After the finished coil has been cemented in place, scrape the insulation from the loose wire hanging over at each end of the coil.

and complete the work on the base. Insert a 1-inch-long 6-32 brass machine screw in each of the holes drilled near the corners of the base. Put a washer and a 6-32 nut over each screw to hold it in place. Do not tighten the nuts—leave them as loose as possible. Mount the coil form on the base, using one brass woodscrew through the right-hand mounting hole. To keep the form flat, support the edge near the screw with spacers made out of cardboard.

Thread the heavy wires attached to the coil through the holes

drilled in the base for this purpose. Wrap several turns of the bare wire around each machine screw. Tighten the nuts at the top of the base to clamp the wires firmly.

Screw a 6-32 knurled nut onto the tip of each screw to complete the binding-post assemblies.

The support for the magnetized needle is made from a 5-inch piece of heavy copper wire (No. 10). Do not use material cut from a coat hanger—the wire used is fabricated from iron or steel and will prevent your galvanometer from operating properly.

Bend the copper wire so that the short leg of the L is $1\frac{1}{2}$ inches long. Insert the long end of the bracket through the hole in the coil and force it into the $1/8$ -inch hole in the base. Cement the bracket in place.

While the cement is setting, magnetize a 2-inch sewing needle by stroking it with a bar magnet. Use one end of the bar magnet and run it from the center of the needle toward the point. Do this several times, stroking the needle in one direction only.

Now stroke the needle in the opposite direction with the other

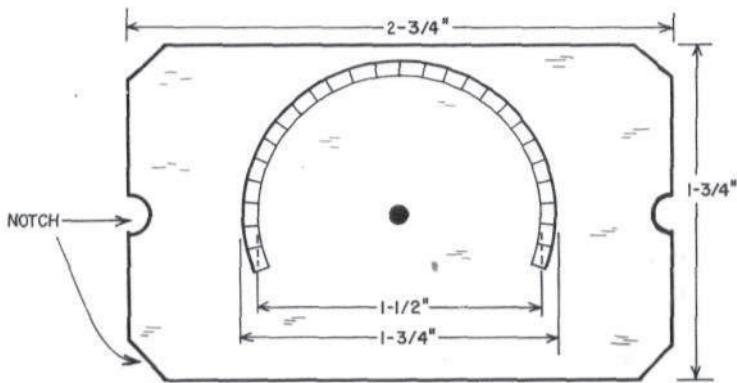


Fig. 206. Trace the meter scale onto a thin piece of card-hoard or stiff white paper. The heavy black dot indicates the center of the scale. Trim the corners for neat appearance.

end of the bar magnet. Again start in the center but, this time stroke toward the eye end of the needle. When you are through, the needle will have been turned into a small permanent magnet. You can find out how successfully the needle has been magnetized by testing it with a small pin. The needle should attract the pin—the odds are that you will not be able to lift the pin from a resting position so that it hangs free from the needle. However,

you will be able to move the pin, proving that the needle is magnetized.

Tie a bit of silk thread onto the needle and attach it to the wire bracket so that the needle hangs above the coil. Slide the needle back and forth in the knot until it hangs level with the coil. When the needle is balanced, place a drop of cement on the knot to fix it in place.

Cut out a thin piece of cardboard or a piece of stiff white paper as shown in Fig. 206. Trace or draw the scale onto the paper as shown. Position the scale so that the center is directly below the knot attached to the needle and cement it directly to the coil. When the cement is dry, your galvanometer is finished and ready to be used.

Using the galvanometer

Before using the meter to detect the presence of electric current, let's see just how sensitive to magnetism it is. Take a bar magnet and place one end of it near the point of the needle. Slowly draw the magnet away from the needle. Notice the resting position. When the needle returns to its normal resting position, reverse the magnet and gradually bring it toward the needle. Notice that the needle begins to swing in the opposite direction. This is because you have reversed the polarity of the magnetic field.

Now that you know how a magnet affects the needle of the galvanometer, you can find out how many things in your house contain magnets. Unplug an electric clock and bring it near the meter and see if the needle moves. Do the same thing with a radio which is unplugged. There are many other objects which you can test this way. You will find that magnets play an important part in everyday living. In the electric clock, a very strong magnet is part of the motor. In the radio a magnet helps run the speaker. These magnets are permanent ones and work all the time—that is, they produce magnetic fields whether or not power is applied to the radio or the clock.

As you already know, the galvanometer will detect the presence of electricity—or so we've said. It's easy enough to prove that an electric current will deflect the needle. Just hook up a battery to the binding posts of the galvanometer. The needle will move, the amount of movement depending on the size of the battery. Reverse the leads to the battery and the needle will move in the opposite direction. This occurs because, when you reverse the battery leads, the magnetic field produced by the current in the coil also reverses.

It is possible to measure the relative strength of an electric current by noting- how many divisions the needle moves when voltages of different strengths are applied to the galvanometer. Try connecting several batteries together and noting the results.

Experiments to try

Experiment 1

Move the N-marked or North pole of a permanent bar magnet within a foot or so of the galvanometer needle. The north-seeking end of the needle will whirl around toward it, indicating that it is the S or South pole of the needle. Remember the magnetic law that opposite poles attract each other, just as opposite electrical charges attract. In some magnetic compasses, the north-seeking end of the needle is plainly marked with an N, to avoid mistakes in direction when they are used for magnetic guidance.

Experiment 2

Turn the bar magnet through a half-circle and the galvanometer needle will reverse its position. Note that the same thing happens when a coil carrying a direct current is substituted and turned slowly near the needle.

Experiment 3

Position a piece of straight wire over the needle, but not touching it or the suspending silk thread. When current from a dry cell is sent through the wire, the needle will whirl around to a position at right angles to the wire. Reverse the current through the wire and the needle will reverse its position, but it will come to rest in its usual north-south direction when the direct current is turned off.

Experiment 4

Now position the direct current carrying wire under the suspended needle and note that the needle moves in the opposite way. Test this by positioning the wire first over the needle, then under it, without reversing the current. You can now reverse the direction of the needle without reversing the current in the wire.

Experiment 5

Suspend a U-shaped permanent magnet over the galvanometer needle with a string attached to the mid-point of the U. Gently twirl or wind up the magnet on its string, then allow it to unwind slowly. Note that the galvanometer needle closely follows each turn of the U-magnet.

a special type of switch which reverses the polarity of the current flowing through the coil at the proper instant. This automatic

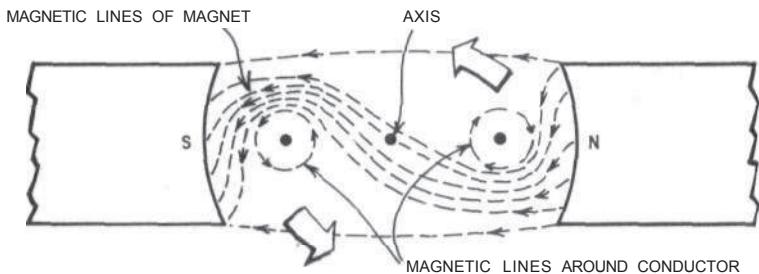


Fig. 302. When a loop of wire is mounted between the poles of a magnet and a current is sent through the loop, the loop rotates in a counterclockwise direction around its axis. The loop has a magnetic field and so does the magnet. A reaction between the two results in a rotating effect called torque.

switch enables the coil to spin itself about its shaft in an efficient manner.

How it works

If a conductor (such as a wire) is placed in a magnetic field and a current is passed through it, the conductor will be caused to move. The force acting upon a current-carrying conductor in a magnetic field depends upon the strength of the field, the length of the conductor in that field and the amount of current flowing through the conductor. The greater any of these components becomes, the greater is the force exerted on the conductor.

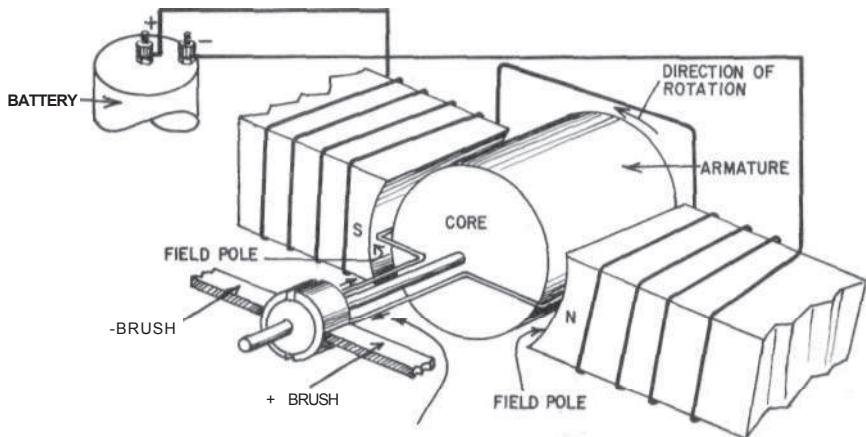


Fig. 303. The armature rotates in a magnetic field set up by electromagnets. The commutator reverses the direction of current flow through the armature.

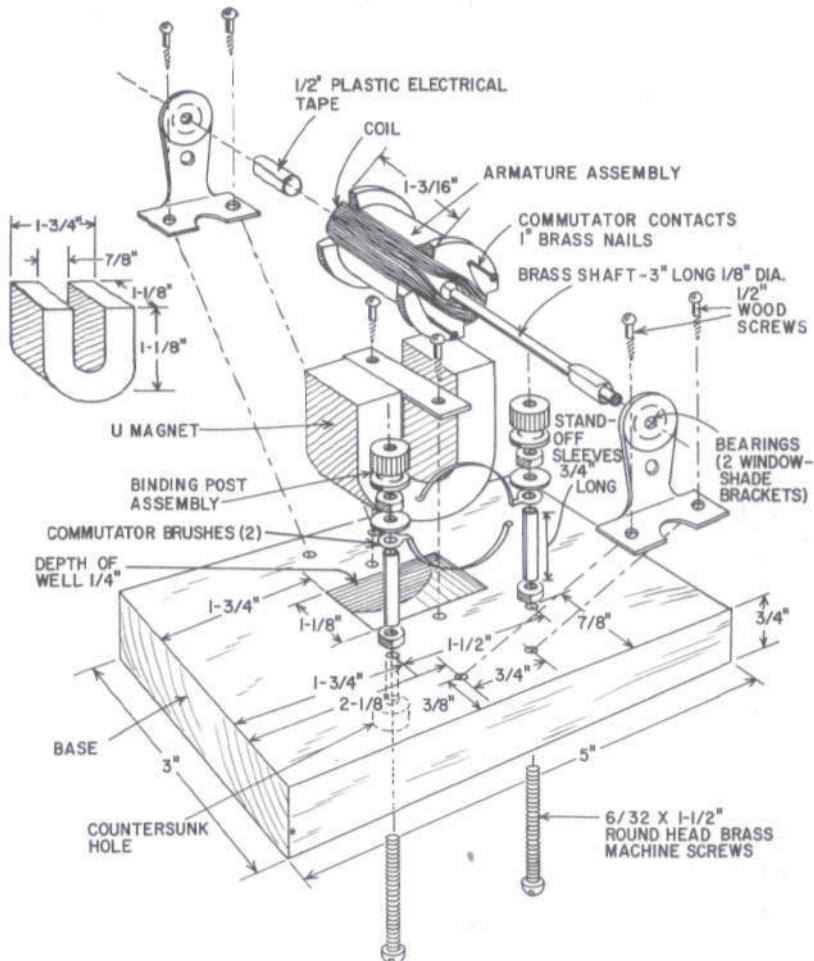


Fig. 304. After the base has been drilled, a $1\frac{1}{8} \times 1\frac{1}{2} \times \frac{1}{4}$ -inch well is chiseled or gouged out and the magnet is mounted in the well, with the poles facing up.

parts list for the dc spool motor

Magnet: Alcomax U type; $1\frac{1}{8} \times 1\frac{1}{8} \times 1\frac{1}{4}$ inches with $\frac{1}{8}$ inch gap (Lafayette F-55 or equivalent).

Wire: spool of No. 28 enameled.

Hardware: 2—6-32 x $1\frac{1}{2}$ inch roundhead brass machine screws; 2—6-32 x 1 inch brass machine screws (see text); 4—6-32 brass hex nuts; 2— $\frac{1}{8}$ inch spacers (make from $3/16$ inch inside diameter brass tubing); 2—brass washers; 2—6-32 knurled nuts; brass or fiberboard strip to hold

magnet in position 6— $\frac{1}{2}$ inch roundhead brass wood screws; 2—1 inch brass nails; 2—window-shade brackets, round hole style; 1—3 inch length of brass rod, $1/8$ inch diameter; strip brass for commutator brushes.

Miscellaneous: spool ($7/8$ inch diameter); wood base, $5 \times 3 \times \frac{3}{4}$ inches; electrical tape; Duco cement; 3-volt battery (RCA VS136 or equivalent).

Suppose a single loop of wire is mounted between the poles of a magnet so that it is free to rotate on its horizontal axis, and we send a current through this loop. One side of the loop is moved down and the other up. As a result, the loop tends to rotate in a counterclockwise direction around its axis. The rotating effect produced by the reaction between the magnetic field of the magnet and the magnetic fields around the conductors of the loop is known as *torque*. It results from the reaction between two magnetic forces or fields.

If a direct current is passed through the loop (Fig. 302), the reaction between the magnetic fields tends to push the left-hand side of the loop down in a counterclockwise direction. However, when the conductor reaches the bottom of its sweep, it encounters an equal and opposite push. It thus becomes stationary. At the same time, the right-hand side of the loop becomes stationary at the top of its sweep. Hence, the result is that the loop remains fixed in its vertical position. This is called the *zero-torque* position of the loop, since there is no rotating effect and no torque.

However, with the aid of the commutator (a rotating electrical switch that turns with the armature), the direction of current flow in the loop can be reversed each time it reaches the zero-torque position, and the loop will continue to rotate counterclockwise.

This is how the dc motor operates. The loop, or *armature*, rotates in a magnetic field, set up by permanent magnets or, more commonly, electromagnets, and the commutator periodically reverses the direction of current flow through the armature (Fig. 303).

Building procedure

Cut a piece of scrap wood $\frac{3}{4}$ inch thick into a 3 x 5-inch rectangle for the base of the motor. Drill the base as shown in Fig. 304. You can use Fig. 305 as a guide in marking the position of the holes.

When the base has been drilled, chisel or gouge 1 1/8 x 1 1/2 x $\frac{3}{4}$ inch well as shown in Figs. 304 and 305. Mount the magnet in the well, with the poles facing up. Some magnets have a hole drilled in them so that they can be mounted with a single brass woodscrew. If your magnet is not drilled, strap it in place with a strip of fiberboard or tin-can metal. Place the strap across the center of the magnet and fasten its ends to the base with woodscrews.

After the magnet is in place, drop the spool between the pole pieces. There should be just enough room for the spool to turn freely. If the fit is too tight, gently sandpaper the spool till it is the right size.

File two slots in the spool as shown in Fig. 304. The slots are $1/8$ inch deep and $3/8$ inch wide. Make sure that you position them directly opposite each other. Cut a 3-inch length of $1/8$ -inch brass rod (welding rod can also be used). Slip the rod through the

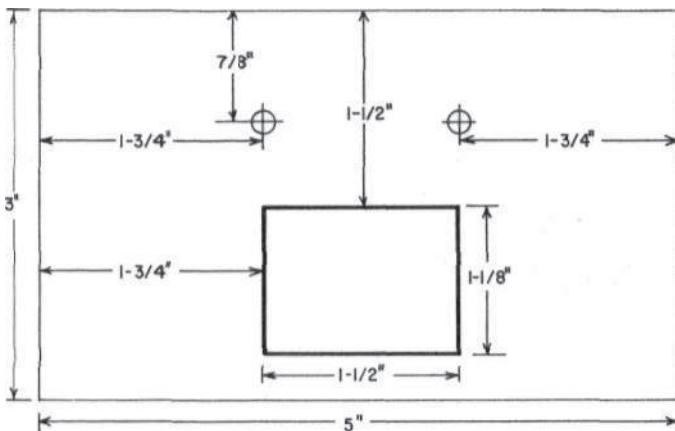


Fig. 305. A guide to help mark the position of the holes when drilling the base of the motor.

center hole of the spool. If the fit is loose, wrap tape or paper over the rod until it fits snugly. Center the rod so that equal lengths protrude from each end of the spool. When the shaft is centered, place some Duco cement at each end to hold it to the spool.

When the cement is dry, wrap two layers of $\frac{1}{2}$ -inch plastic electrical tape around the ends of the shaft as shown in Fig. 304.

Before we begin to wind the armature coil, the commutator contacts must be placed in position. Drive two 1-inch brass nails into the end of the spool as shown in Fig. 304. Leave about half the length of each nail protruding.

The first step in winding the armature coil is to strip $\frac{1}{2}$ inch of insulation from the end of a spool of No. 28 enameled wire. An easy way to strip the enamel insulation is to rub it off with a piece of fine sandpaper. You can also scrape it with a penknife. In either case, be sure to remove the enamel completely. You are *going to* solder the end of the wire to *one* of the commutator contacts, so the bare metal must be exposed.

Wrap the bare end of the wire around one of the brass nails as close to the spool as possible. Carefully solder the wire to the nail.

Wind 10 turns of wire in the slots cut into the spool. Wind these on the same side of the shaft as the nail to which the wire is soldered. Wind another 10 turns on the other side of the shaft. Then alternately wind 5 turns on each side of the shaft until you have wound 40 turns in all.

When the coil is completed, pull the loose end of the wire tight. Bring this end to the remaining bare nail and cut off any excess. Strip the end of the wire clean of all insulation and solder it to the nail. If any of the turns of the coil stick out beyond the body of the spool, press them firmly in place and cement them down.

When the cement is dry, drop the armature in place between the poles of the magnet with" the brass nails facing the side which has been drilled for the binding posts. Take two window-shade brackets and place them in position as shown in Fig. 304. Insert the ends of the armature shaft in the bearings and move the assembly around until the armature can revolve freely between the pole pieces of the magnet. Carefully mark the position of the bearing mounting holes with a scribe or punch. Then, using the punch marks as a guide, attach the bearings to the base while the armature is in place. Before tightening the bearing mounting screws, make any final adjustments needed to allow the armature to turn.

When the armature and bearings are in place and you are satisfied that the armature moves easily, you are ready to install the commutator brushes.

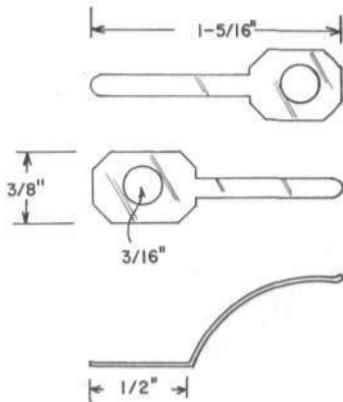
You can trace the pattern for the brushes onto a piece of paper (Fig. 306 is drawn to the proper size) and cement the paper to thin sheet brass, copper or tin-can metal. An easier way to transfer the pattern is to place a piece of carbon-paper over the sheet metal you are going to use. Carefully insert the carbon-paper-metal sandwich under Fig. 306. Go over the outline of the brushes with a hard pencil or a ballpoint pen. The carbon paper will transfer the pattern to the metal.

Because thin sheet metal is difficult to drill, punch the mounting holes in the brush material before you cut out the individual brushes. Use an icepick or sheet-metal punch to penetrate the metal. Enlarge the holes to the proper size by working the tool around with a rocking motion. After the holes are the proper size, cut out the brushes with a pair of shears. If you used a paper

template, remove the paper from the brushes before bending them to the shape shown in Fig. 305.

Before mounting the brushes, it is necessary to determine the proper angle for mounting them. Strip 1 inch of insulation from each end of two 1-foot lengths of wire. Attach the wires to a 3-volt battery. Next, position the armature so that the windings are between the pole pieces of the magnet. Hold one wire from the battery in each hand and touch them to the commutator nails as shown in Fig. 307. If the motor does not begin to turn, have someone give the shaft a gentle twist in either direction to get it started. As the motor spins, tilt the wires in a clockwise direction (Fig. 307). Keep the wires parallel to each other as you move them. When you have gone as far as possible in one direction, tilt the wires in the opposite direction. As you alter the angle to the commutator contacts, you will find one position at which the motor turns the fastest. This is the angle at which you should mount the brushes.

Fig. 306. This pattern can be used for the commutator brushes. Trace the pattern onto a piece of paper and cement the paper to thin sheet brass, copper or tin-can metal.



If the proper angle is nearly vertical, mount the brushes directly to the base. This is easily done by omitting the standoff sleeves indicated in Fig. 304. Insert 6-32 x 1-inch machine screws through the base and fasten them in place with 6-32 nuts. Slip the brushes onto the screws and fix them in place with nuts. Then bend the brushes to the proper angle. Top off the assembly with brass washers and knurled nuts.

If you found the best angle for the brushes close to the horizontal, as in the author's model, you will have to build up the binding posts as shown in Fig. 304. Insert 6-32 x 1½-inch machine screws through the bottom of the base and fasten them with 6-32 nuts. Then cut two ¾-inch lengths of 3/16-inch inside diameter

metal tubing. Drop the tubing over the machine screws and place the brushes on top of the tubing. Place a washer over each brush and fasten them in place with 6-32 nuts. Finish off the binding posts by placing knurled nuts on top of the assembly.

Using the dc spool motor

A two-pole spool motor such as you have just built is not an extremely powerful device. It will not, for instance, produce enough power to drive a small automobile. However, it does spin very rapidly. If the armature is well balanced and turns freely, a 3-volt battery will provide enough current to run the motor. By using a 4.5-6-volt battery, however, you will be able to get much more power from your motor.

To extend its life, put a bar of scrap iron or steel across the top of the magnet (across the poles). The bar can be any convenient length. Three or four soft-iron nails placed side by side will also do.

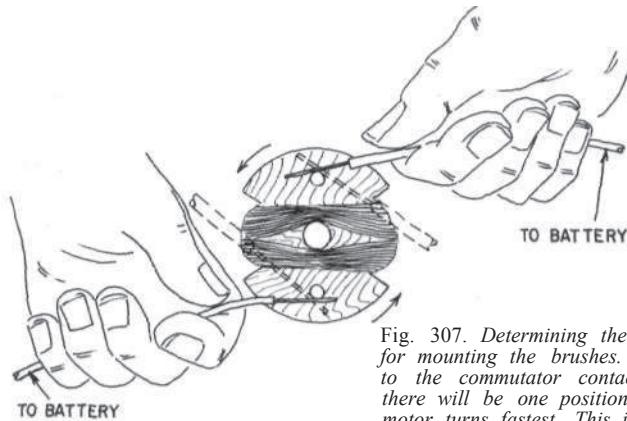


Fig. 307. Determining the proper angle for mounting the brushes. As the angle to the commutator contacts is altered, there will be one position at which the motor turns fastest. This is the angle at which the brushes should be mounted.

The bar or the nails used in this way is known as a keeper. Remove the keeper when you want to operate the motor. You won't need to fasten the keeper in place, since the magnet will hold it securely.

Experiments to try

Experiment 1

Put the motor to work by making a small propeller from cardboard and attaching it to the shaft. You'll be surprised at the big breeze this little unit is capable of producing.

Experiment 2

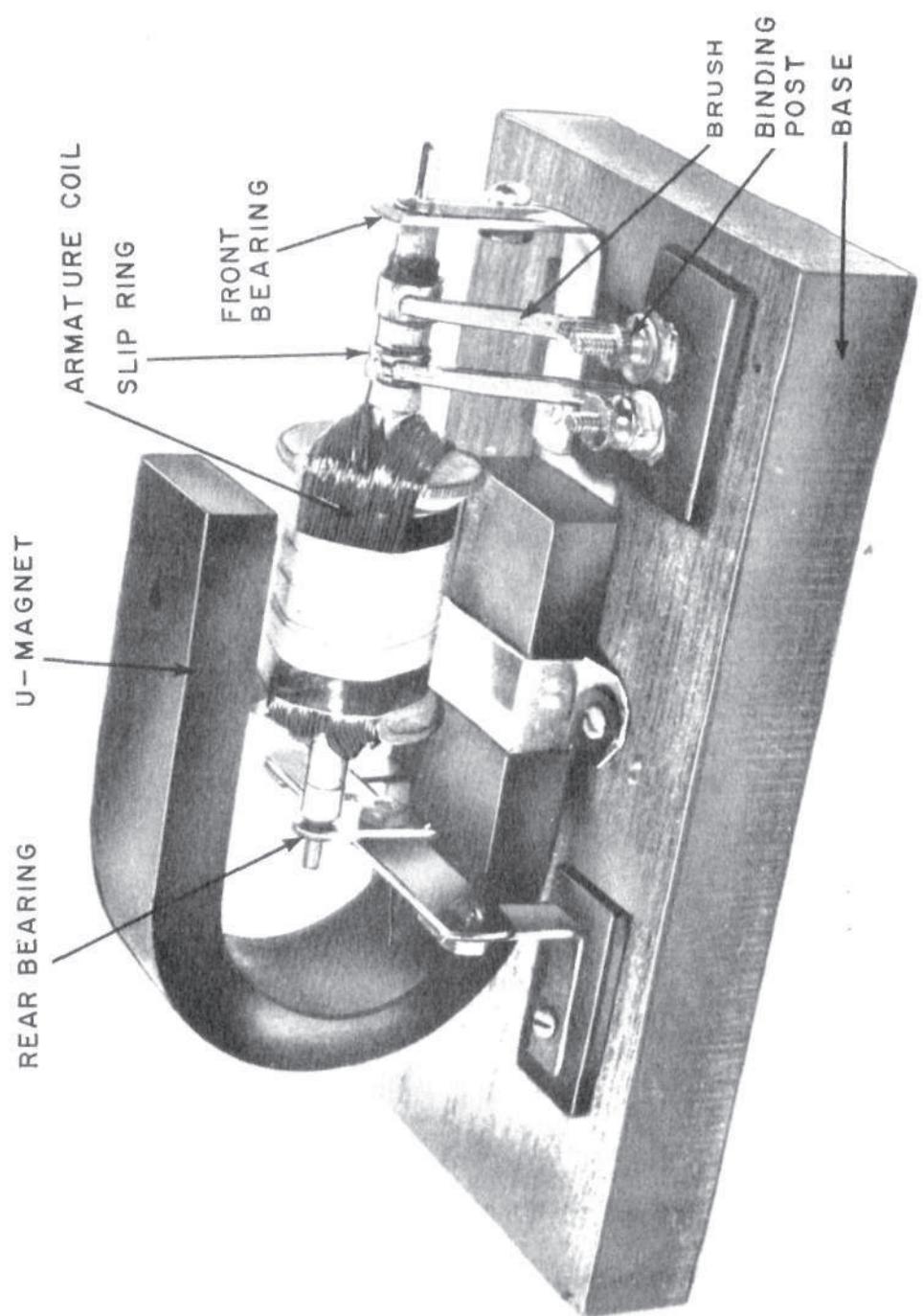
You can put the motor's speed to work by attaching a small pulley to the shaft and a larger pulley to, let us say, a model ele-

vator. The second pulley will not turn as quickly but will deliver a lot more power than you can get directly from the shaft of the motor.

Experiment 3

To show further the interaction between a magnetic field and an electric current, your spool motor can be used to generate electricity. When an electric current moves through a coil of wire, it produces a magnetic field. Also, when a coil of wire is moved in a magnetic field, an electric current is produced in the coil.

We can prove this by disconnecting the battery from the electric motor and connecting the motor to our galvanometer. Use very long wires to make the connection so that the magnet does not make the galvanometer needle move. When you have made the connection, wrap a yard or so of thread around the motor shaft. Pull one end of the thread and as it unwinds, the armature will spin in the magnetic field. Watch the galvanometer to see if the needle moves. It will probably swing a very small amount, indicating that we are generating some electric current. Only a small amount of current can be generated because the armature coil does not have very many turns—the amount of current generated depends upon the number of turns in the coil, the strength of the magnet and the speed at which the coil moves. Although we are moving the coil rapidly in a relatively powerful field, the number of turns is small enough to keep the electrical output low.





building ac generators

ONE day in the summer of 1831, Michael Faraday — often called the Columbus of the Electrical Age — was tinkering at the Royal Institution in London with an iron ring on which he had wound two coils of wire. His purpose was to send an electric current through the coils and so magnetize the ring.

Faraday, however, had connected one of the coils to a small galvanometer. When the other coil was attached to a battery, the galvanometer needle moved violently, but soon stopped. This surprised him at first, but Faraday concluded finally that the current that caused the needle to move had been sent somehow through the magnetic link between the coils.

Electricity, he knew, could produce magnetism in the iron, but now he also knew that the reverse was possible — a magnetic force could produce electricity. Faraday, who was one of the greatest experimenters in all electrical history, called his discovery *magnetic electricity*. It proved to be one of Faraday's greatest — a forerunner of today's induction coil, the electric transformer, the magneto-telephone, the motor, and the electro-dynamo.

Faraday reasoned that since a current flowing in a wire generated magnetism and caused a needle to swing, the reverse should be possible — magnetism should produce an electric current.

Faraday formulated the laws of electromagnetic induction and proved them right by suspending a wire so it could rotate between

 Fig. 401. *The idea that magnetism could produce an electric current led Faraday to the laws of electromagnetic induction and resulted in his invention of the ac electric generator.*

magnetic poles, thus demonstrating the basic principles of the electric motor and which led to his invention of the electric generator (Fig. 401).

So we know that electric generators, or dynamos, are basically exactly like electric motors. This similarity is especially so in dc machines, which can either be attached to an electric circuit and produce mechanical power or rotated by a belt-driven pulley and produce dc electricity.

Alternating current motors and generators

But motors and generators designed for ac (alternating-current) operation — the type of electricity wired into your home to run the refrigerator, the TV set and electric lights — are often quite different, so much so that one type of machine usually will not operate on the other type of current.

What is this difference, since all motors and all generators are so alike in so many other ways? First, all generators, whether dc or ac, initially produce ac in their armature windings as they spin around within the field of the magnetic poles. In dc machines, a rotating electrical switch changes the ac to dc. These switches are called commutators. They consist of a circular arrangement of insulated copper bars attached to the armature windings.

As electricity is induced in each winding, contact is made between the commutator bars and a system of electrical brushes, thus delivering direct current to the outside circuit. In other words, the commutator rectifies the ac, so the current flows in one direction. (We also used commutators in our dc motor.)

How it works

The ac generator, on the other hand, has special kinds of rotating contactors, called *slip rings* which, when equipped with brushes that slide over the continuous surface of the rings, conduct the ac generated in the armature coils directly and continuously to the outside circuit. Fig 402 is a simplified diagram of the ac generator of Fig. 401.

The alternating current delivered to your home changes its direction of travel in a wire circuit 120 times each second. This produces what is known as 60-cycle alternating current — one cycle, normally, for each complete revolution of the generator's armature.

Alternating current is the universal type of electrical power today because it has so many more commercial applications than dc. It can be easily generated and transformed to high or low

voltages for long and short-distance transmission, thus effecting larger power savings than possible with dc.

These are only a few of the reasons why it is so important to become familiar with the principles of this type of generating machinery, and the wooden-spool ac generator is a step in that direction. Of course, actual ac generators (and dc, too) do not employ wooden-core armatures, but make use of specially designed soft-iron cores with two or more slots machined around their circular edges. The armature coils are wedged firmly in these slots so the wires pass close to the poles of the wirewound magnets as the armature rotates. This greatly increases the dynamo's electrical efficiency.

Building procedure

Prepare a base $4 \times 7 \times \frac{3}{4}$ inches from scrap wood. Drill it as shown in Fig. 403. Next cut a strip 3 inches long and $\frac{3}{4}$ inch wide from a tin can and punch holes near its ends. Fix the magnet in place with the sheet-metal strip as shown.

File or chisel $\frac{3}{4}$ inch wide by $\frac{3}{8}$ inch deep slots on opposite

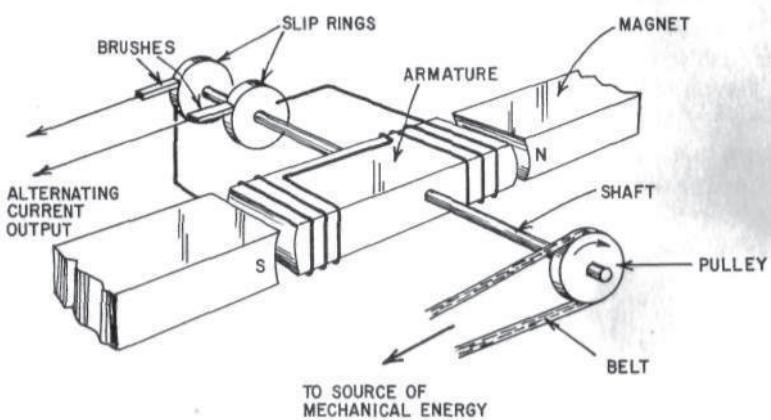


Fig. 402. Simplified illustration of our ac generator.

sides of a large wooden spool. The larger the spool the better, but make sure that it will turn freely between the poles of the magnet used.

Since the holes through large-size spools vary in diameter from $5/16$ to $3/8$ inch you will have to measure the hole in the spool you are going to use. If at all possible use the smaller size. Next, cut a 4-inch length of dowel of the proper diameter to fit the hole.

Place the dowel in the spool so that $\frac{3}{4}$ inch extends from one side of the spool and the balance from the other. Cement the dowel in place.

Mark the exact center of each end of the dowel shaft with an icepick or a punch. Starting with a small-size bit, drill out the center of each end about $\frac{3}{4}$ inch deep. Use progressively larger drills until a short piece of 1/8-inch diameter brass rod can be put into the openings. Cut two 1 $\frac{1}{2}$ -inch lengths of rod, and hammer one end of each until you have made a small flat surface on it. Apply cement to the flattened end of each rod and force them into the openings made in the dowel. The two rods should now project $\frac{3}{4}$ inch from the ends of the dowel. These metal extensions will fit into the armature bearings and are used to reduce friction.

Wrap the wooden dowel shafts with a layer of plastic electrical tape. This will keep the wood from splitting when the generator is in use.

The armature coil is wound in almost the same manner as that of the dc spool motor. However, since there are no commutator contacts to anchor the wire, make a slit in the edge of the spool to hold the end of the wire while winding. The slit is made on the edge of the spool near the long end of the shaft. Wedge one end of a reel of No. 30 enameled wire into the slit, leaving about 3 inches of the free end hanging over. Wind 50 turns of the wire in the slots, keeping all of the turns on one side of the shaft. Wind the next 50 turns on the other side of the shaft. Continue to alternate the turns in groups of 50 until a total of 500 is wound. When the coil is completed, cement and tape the windings in place.

Take one end of the winding and lay it down on the dowel shaft. Wrap one or two layers of tape around the wire as shown in the insert of Fig. 403. End the tape wrapping about $\frac{1}{2}$ inch from the end of the wooden shaft.

parts list for ac generator

Wire: Spool of No. 30 enameled

Magnet: U-type (horseshoe), 1 inch gap.

Base: wood, 4 x 7 x $\frac{3}{4}$ inch.

Hardware: metal strip (tin) 3 x $\frac{3}{4}$ inch; 3 inch length of brass rod, 1/8 inch diameter; 2—3/16 inch lengths of copper or brass tubing, $\frac{1}{8}$ inch inside diameter; 2—sheet brass for brushes, $2\frac{1}{2}$ x $\frac{1}{2}$ inch; 2—6-32 knurled nuts; 7—6-32 hex nuts; 2—6-32 x 1 inch brass machine screws; 2—6-32 x $1\frac{1}{2}$ inch brass machine screws; 1—6-32 x $\frac{1}{2}$ inch brass machine screw;

2—1 x 1 x $\frac{1}{2}$ inch brass L brackets; 1—1 x $\frac{1}{4}$ inch brass L bracket; 1—3 x 1/8 inch sheet brass for crosspiece; 1—1 x $\frac{1}{4}$ inch sheet brass for rear bearing; 6— $\frac{1}{4}$ inch brass roundhead woodscrews; washers—as needed; fiberboard spacers — as needed; 1—fiberboard 1 x $1\frac{1}{4}$ inch; 1—fiberboard 1 x $1\frac{1}{2}$ inch.

Miscellaneous: 6-volt battery; large spool; dowel—4 inches long to fit in spool; Duco cement; electrical tape.

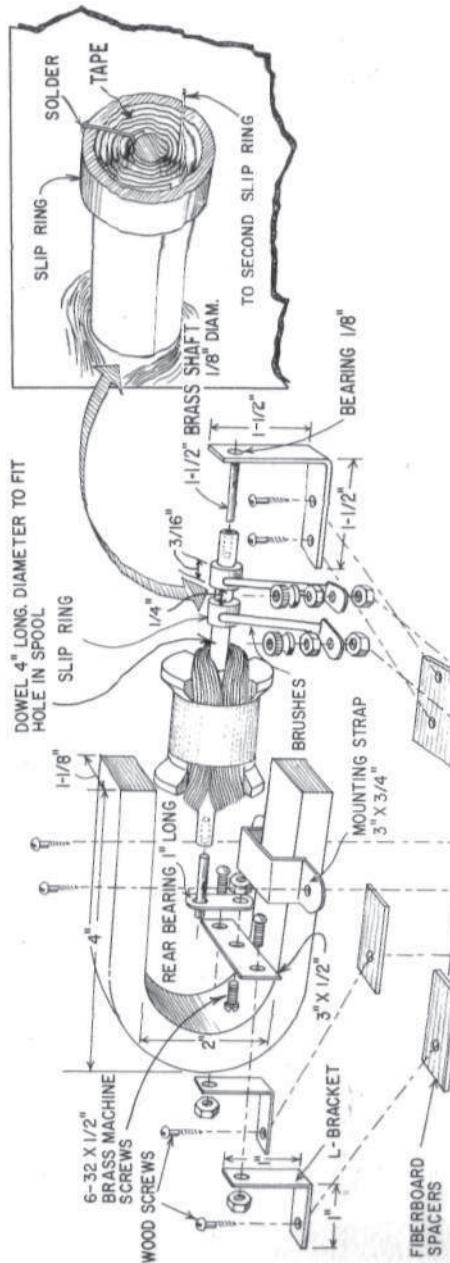
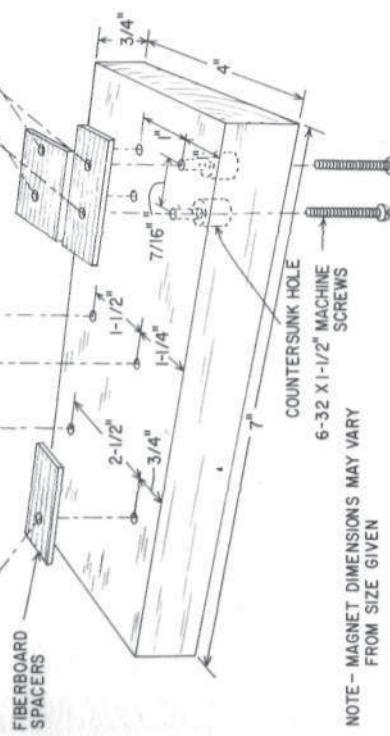


Fig. 403. Exploded view of the electric generator. The insert will help you follow the positioning of the slip rings.



NOTE - MAGNET DIMENSIONS MAY VARY
FROM SIZE GIVEN

Place the remaining end of the coil on top of the tape wrapping and cover this wire with several layers of tape. The second layer of tape should end about 1 inch from the end of the wood dowel.

Trim the ends of the leads coming from the coil to a length of about $\frac{3}{4}$ inch and gently remove the insulation.

Cut two 3/16-inch lengths of 3/8-inch inside diameter copper or brass tubing. (With a 3/8 inch dowel use $\frac{1}{2}$ -inch tubing.) File or sandpaper any burrs left on the lengths of tubing until smooth. Clean the outside surface with steel wool until the metal is clean and shiny.

Carefully tin the outside surface of each ring, placing the solder near one edge of the tubing.

Place the sections of tubing on the long end of the dowel shaft of the armature. They are going to be used as the slip-rings, and the leads coming from the coil will have to be soldered to them. Place the innermost slip ring between the short lead and the spool. Position it so that the outer edge is about 1 inch from the end of the wooden shaft. Solder the short lead to the outer edge of the slip ring as quickly as you can. Because the slip ring has been tinned, this should be fairly easy.

Position the other slip ring $\frac{1}{4}$ inch from the first and solder the longer lead to it. The insert of Fig. 403 will help you to follow this process. Fig. 404 is another detailed view of the slip ring assembly.

Cement the slip rings in place as shown in Figs. 403 and 404. After the cement has hardened, gently file any excess solder from

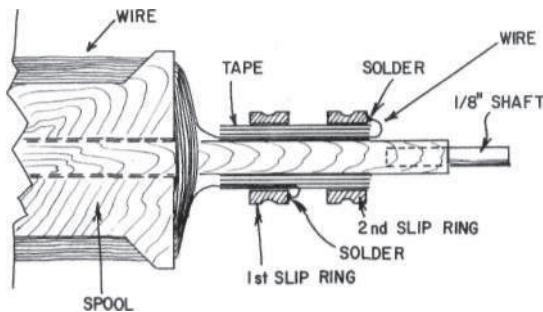


Fig. 404. Detailed view of slip ring assembly.
Note how the slip rings are fastened in place.

their surfaces. Give them a final polishing with fine sandpaper and steel wool.

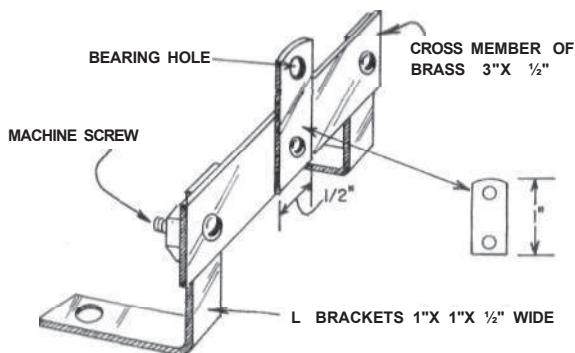
The next step in the construction of the generator is the

preparation of the front and rear bearings. The front bearing is a $1\frac{1}{2}$ -inch brass L-bracket mounted on a $1\frac{1}{4} \times 1$ -inch fiberboard base, as shown in Fig. 403. You may have to enlarge one of the holes in the L-bracket to fit the metal shaft of the armature. To do this use a small rat tail file.

Mount the bearing with woodscrews as shown. You may have to adjust the height of the bearing to center the armature between the poles of the magnet. The easiest way to do this is to place washers between the bracket and the base. If the bearing is too high, remove material from the base with a file or sandpaper.

The rear bearing bracket is made from two 1-inch L-brackets and a crosspiece. Assemble the brackets and the crosspiece as shown in Fig. 405. The bearing itself is a 1-inch piece of brass

Fig. 405. Mounting the rear-bearing bracket. The bracket is made from two 1-inch L-brackets and a crosspiece of brass $3 \times \frac{1}{2}$ inch.



stock drilled as illustrated in Figs. 403 and 405. Attach the bearing to the crosspiece as shown. Mount the rear bearing assembly to the base with woodscrews. Notice that small blocks of fiberboard are used between the L-brackets and the base to provide the necessary height. If the front and rear bearings do not line up vertically, adjust the height with washers. There will be sufficient play in the rear bearing to make any horizontal adjustments before tightening the assembly screws completely.

When the bearings are in place, slip the front end of the armature shaft (slip ring end) into the front bearing and the rear end into the rear bearing. Tighten the rear-bearing mounting screws and make sure that the armature spins freely. Readjust the bearing height if necessary at this time.

Punch or drill two 1 1/8-inch holes in a piece of fiberboard 1 x 1½-inches. Space the holes so that they correspond to the countersunk holes drilled in the base for the binding-post brush assemblies (Fig. 403). Insert two 6-32 x 1½-inch machine screws in the holes and place the fiberboard block over them. Fasten the screws in place with two nuts.

Trace the templates for the brushes from Fig. 406. Punch the holes in the sheet metal used and cut out the brushes. Place the brushes over the protruding machine screws, and fasten them in place with nuts. Top off the assembly with knurled nuts. Bend the brushes so that they contact the slip rings as in Fig. 403 and the generator is complete.

Give the armature a final turn to make sure it will spin freely. Oil the bearings with light machine oil to make the action as smooth as possible.

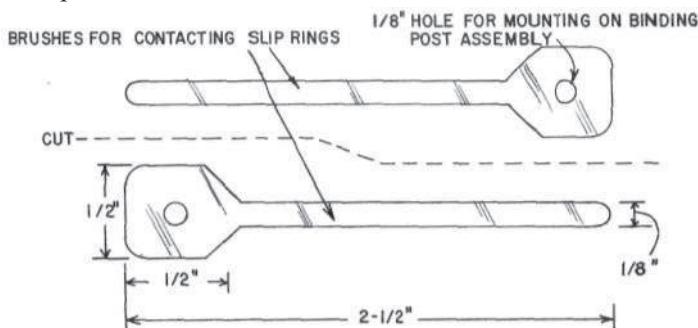


Fig. 406. The templates for the brushes for contacting the slip rings can be traced from this illustration.

Using the ac generator

Although the ac generator uses slip rings, it is still capable of motor action. Connect a 6-volt battery to the binding posts of the generator and the armature will try to turn. It will move only through part of a revolution, however, because the current flows in a single direction. If you rhythmically remove and reinsert one of the wires from the battery, you will be able to make the armature spin. However, since the current is being only interrupted and not reversed, the armature will probably turn in a somewhat sluggish manner. The generator, however, will function as a motor on alternating current.

If you have an electric-train transformer, attach it to the generator. (*Do not* under any conditions attach the generator directly to your electric power outlet). When you turn on the power to

the generator, you will hear a buzzing sound as the current reacts with the magnetic field. Wind a yard or so of string around the armature shaft and give it a sharp pull with the power on. If you spin the armature fast enough, it will continue to turn at a rate determined by the alternations of the 60-cycle current from the transformer. You have to use the string to start the armature spinning because, unlike most motors, we did not use special starting coils.

The ordinary electric-clock motor is essentially like your ac

3 VOLT POCKET FLASHLIGHT BULB OPERATED BY GENERATOR

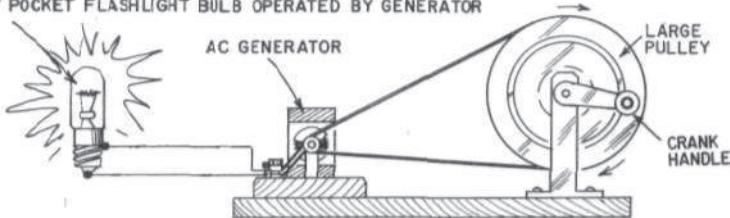


Fig. 407. Current produced by turning the large pulley quickly will cause the 3-volt flashlight bulb to glow. The faster you turn, the brighter the bulb will light.

generator. You can see that this is a great advantage since the rate at which the motor spins is determined by the frequency (number of cycles each second) of the current. By keeping the ac at a steady 60-cycle rate, the supplier of your house current insures the accuracy of your electric clock.

If the transformer you use is of the variable type, you can see just how great an influence the frequency has. Increase the amount of voltage fed to the generator (do not exceed 12 volts). You will notice that even though you almost double the voltage, the speed of the armature remains fairly steady. Because the motor turns in step with the frequency, it is called a synchronous alternating-current motor.

To use the generator to produce alternating current, the armature will have to be turned at a fairly rapid rate. You can do this by attaching a grooved wooden pulley to the brass shaft of the generator. The pulley should be about $\frac{3}{4}$ inch in diameter.

Make another pulley about 8 inches in diameter and fix it to a shaft mounted on a block of scrap wood. Put a 3-inch length of dowel on the larger pulley, at the center, to act as a crank. Attach a loop of string or a large rubber band between the pulleys as shown in Fig. 407.

Connect a 3-volt lamp, such as is used in a flashlight, across the binding posts of the generator (Fig. 407). Turn the large pulley

quickly and note the glow caused by the current passing through the lamp. As you increase the rate of speed, the glow will become brighter. Reversing the direction in which you turn the crank will have no effect on the glow of the lamp.

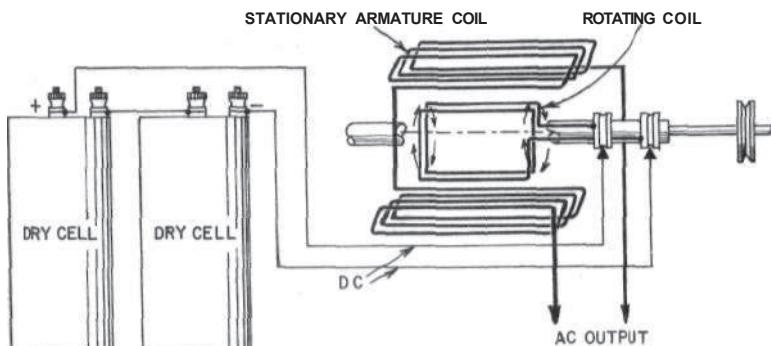


Fig. 408. Simplified illustration of a rotating-field ac generator.

The rotating-field ac generator

The generators used to produce the electrical power for our homes and for industry are large, complex machines. Because huge amounts of power are required, the size of permanent magnets would be so great that they could not be used. Electromagnets are used instead. The highly simplified representation of a commercial generator (Fig. 408) shows another important departure from the generator we built. What is the armature (electrically) is the stationary element in the generator. The magnetic field coils are the moving elements. In practice, large amounts of electrical energy are used to power the field coils; however, we can put together a rotating-field generator powered by batteries by making a few simple alterations on the stationary-field generator.

All that we will have to do is remove the permanent magnet from the ac generator and wind new armature coils. We will use the old armature and slip ring assembly as the moving-field coil. By changing the armature into an electromagnet and spinning it between coils, an alternating electrical current will be induced in the coils. In practice, it does not make too much difference if you move a coil in a magnetic field or if you move the field while the coil stands still—electricity results from either action.

Building procedure

Loosen the woodscrews holding the mounting strap of the U-magnet in place. Remove the strap and the magnet from the base and set them aside.

Cut two pieces of thin cardboard to the size shown in Fig. 409. Fold them as shown in Fig. 410 into rectangular coil forms. Use tape or cement to join the edges of the forms so that they maintain their shape.

Wind 75 to 100 turns of No. 30 enameled wire on each form. Make sure that you leave several inches of wire hanging loose from each end of each coil. Use cement to fix the windings in place.

Although for the sake of convenience we use two separate coil forms, the winding is a single coil, split in the middle so that it can straddle the rotating field. Connect the two windings of the coil by soldering the beginning of one winding to the end of the other. Clean the ends of the wires, twist them together and solder.

Mount the stationary coil in the position shown in Fig. 410. The closer you can get the windings to the rotating element the more efficiently the generator will operate. The coils are fixed in place by cementing them to small wood blocks attached to the base.

Drill two holes in any convenient place in the base and make binding-post assemblies. Connect the leads from the stationary coils to the binding posts to make convenient tie points.

Using the rotating-field ac generator

Attach a 6-volt battery to the binding posts connected to the brushes. This battery supplies current for the rotating field. Connect a 3-volt lamp to the stationary coil and turn the field with the same pulley arrangement you used before. If you placed the

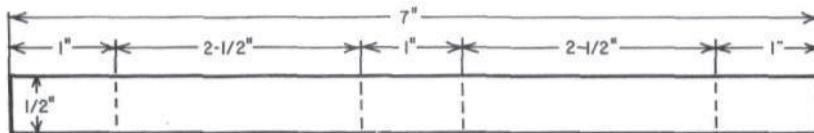


Fig. 409. Two pieces of thin cardboard are cut to the size shown and then folded into rectangular coil forms.

coils close enough to the field, you may find that the lamp glows more strongly than it did with the permanent-magnet type unit. Caution: Whenever you use this type of generator, always disconnect the batteries when you are through. If you leave them connected, they will go dead in a relatively short period of time.

As did the permanent-magnet generator (often called a magneto), the rotating-field generator will produce motor action. Disconnect the lamp from the coils and connect the coil leads to a low-voltage source of alternating current such as an electric-train transformer. Spin the rotating coil with a piece of thread

and note the action. This is another form of the synchronous motor.

The generator will work a little better as a motor if you change the connections. Attach the battery to the stationary armature and connect the ac source to the rotating field. When we do this, the relative positions of the components become the same as in the magneto. The stationary coils form a fixed electromagnet, and the rotating field coil once again becomes an armature. Wrap some thread around the shaft of the armature and spin the shaft. The motor action will be evident again. This is still another form of the synchronous motor. Basically, all three forms are the same—in all cases we have a magnetic field of constant polarity and another field whose polarity changes at a given rate (60 cycles a second), determining the speed at which the motor rotates.

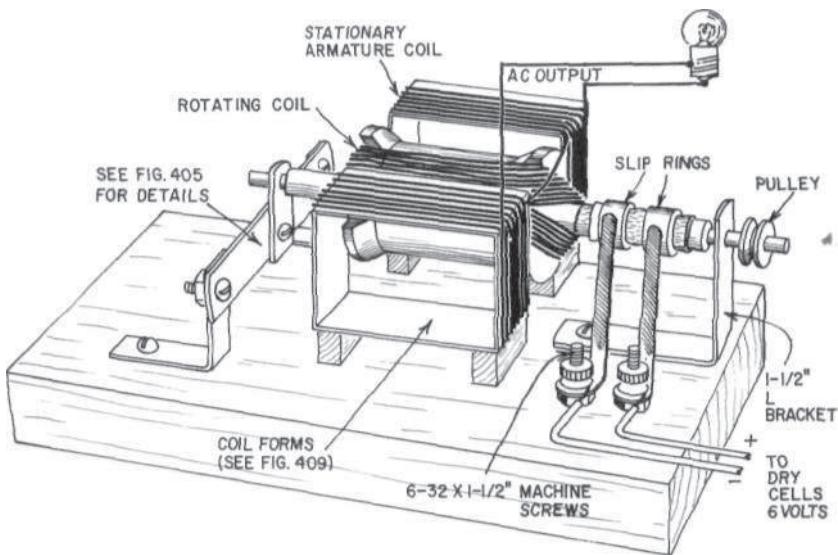


Fig. 410. The completed rotating field generator. Each stationary armature coil is cemented to two small wood blocks attached to the base.

Experiments to try

Experiment 1

Connect wires from a 6-volt battery to the binding posts of the spool ac generator or dynamo. Note the tendency of the armature to rotate as a motor through part of a revolution, indicating that the dynamo is indeed a motor, except for the use of slip rings instead of a conventional two-segment commutator.

Experiment 2

Prove step 1 by touching one of the battery wires intermittently to one of the binding posts, in step or in *synchronism* with the short kicks of the armature, thus performing manually the function of a commutator. If this is done carefully, the armature will continue to rotate.

Experiment 3

Prepare a 117-volt 60-cycle connection from a light socket and insert an electric light socket in one of the two wires, with a 15-watt lamp inserted therein to limit the current flow (Fig. 411). By touching the two wires, the lamp will light. Then apply the same two wires momentarily to the binding posts of the ac dynamo. A buzzing sound will be noted, indicating ac flowing through the armature winding and reacting with the magnetic force of the dynamo's poles. (Be careful not to touch the exposed ends of the wires going to the lamp and to the outlet. Pull the plug out of the outlet when the lamp is not being used.)

Wind a yard of stout cord around the dynamo's wooden dowel (on the end opposite the slip rings). Pull the cord, thus spinning the armature. If the rotation is fast enough, the armature will

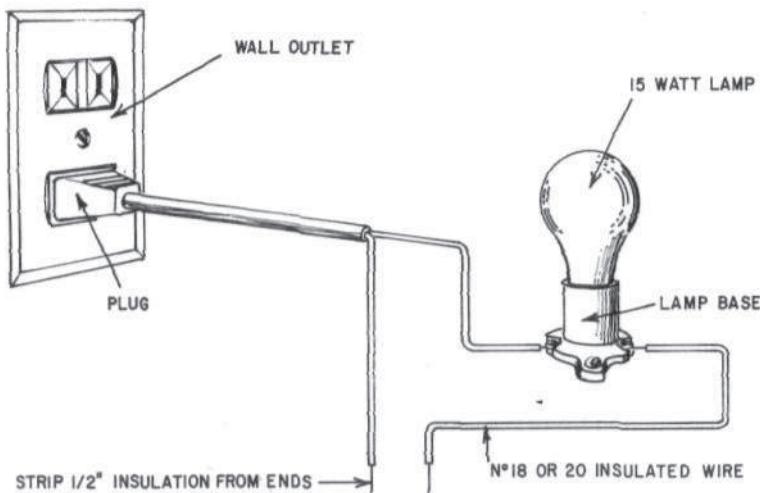
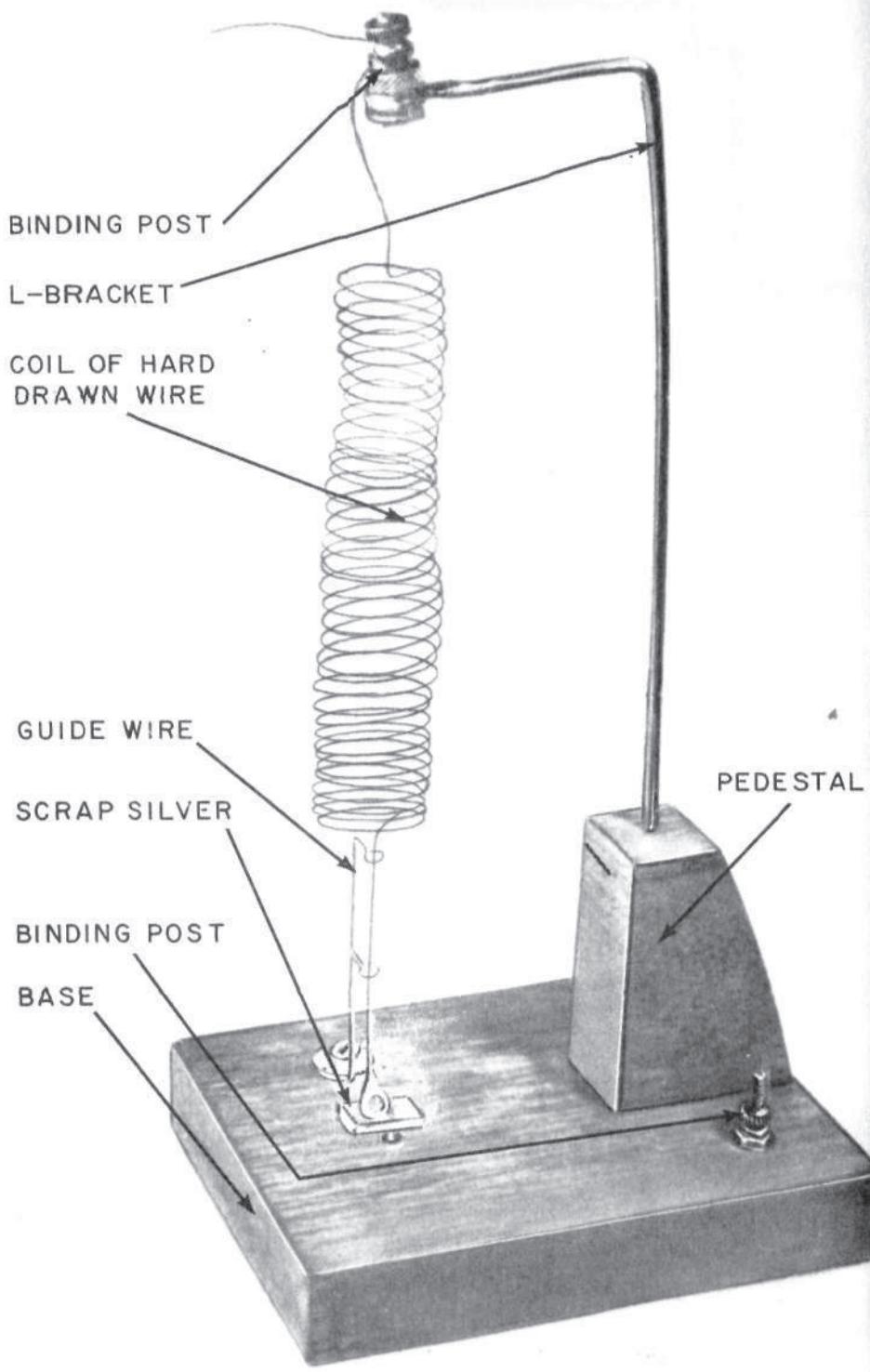


Fig. 411. With the help of a 15-watt lamp, the line voltage can be used to operate the dynamo as an ac motor. Be careful. Do **not** touch the exposed ends of the wires.

continue to turn in synchronism with the 60-cycle ac from the light socket. The dynamo is thus operating as a simple synchronous ac motor.





building an electrical jitterbug

MORE than 100 years ago, an English physician retired from his medical activities to devote the remainder of his life to literature, mechanics and electricity. In due time, he published a volume of English words and phrases, now known throughout the world as Roget's International Thesaurus.

But Peter Mark Roget's interest in scientific fields led finally to his invention of a peculiar device that illustrated the magnetic attraction between the coils of wire of a spiral, suspended vertically, through which an electric current was passed. This single device, known today as *Roget's jumping or dancing spiral*, enrolled his name forever among the pioneers whose thought and dexterity helped build our present world of electricity.

The project we are going to build — the Roget dancing spiral — is shown in finished form in Fig. 501.

How it works

Roget's simple little experimental toy — for that was what it was at first — illustrates one of the basic truths of electrical circuitry: *parallel wires carrying electric currents in the same direction attract each other*. Roget knew, of course, like all experimenters, that the reverse also would be true, as all related electrical phenomena have an action and a reaction. He knew that wires carrying currents passing in opposite directions repel each other.

Fig. 501. *Roget's jumping spiral*. The device illustrates the magnetic attraction caused by passing an electric current between the coils of a vertically suspended spiral.

It was most convenient, however, for Roget to construct his *electrical jitterbug* by suspending a wire spiral from one end, allowing the other end to make and break the electrical circuit in a cup of mercury. As the turns of wire squeezed together upon the passage of electricity, the electrical circuit in the cup of mercury was broken and gravity caused it to descend and contact again, and so on, until the current was turned off.

The mutual attraction between adjacent coils of Roget's spiral may be greatly increased by lowering an iron rod or nail within the coils, thus increasing the magnetic effect or attraction between the wire turns. Thus, as we have learned from Faraday and Maxwell — and will learn from the works of America's Faraday, Joseph Henry, whom Faraday had excelled by demonstrating the first electric motor and dynamo — iron placed in a coil of wire increases its *inductance*, which is a measure of its *flux* or magnetic strength. This strength is measured in units called the *henry*, after the American physicist whose researches in electromagnetism became the basis for the development of the telegraph, telephone and, later, wireless or radio.

What Roget did with his spiral jitterbug was to demonstrate clearly and forcefully, with an exceedingly simple toy, not only the laws of the electric motor and generator, but also the solenoid or suction coil, the electromagnet and countless other instruments of modern electrical equipment.

Building procedures

As in previous electrical models, begin by preparing a 3 x 5-inch base, varnish with mahogany stain, and wipe away the excess.

Attach to the base, using glue and one or two 1 1/2-inch brads, a 2 1/2-inch high pedestal (shaped as shown in Fig. 502) as a convenient fixture or stand for a 9-inch piece of No. 10 or 12 bare copper wire to support the spiral. Construction details for the base and pedestal are shown in Fig. 503.

Prepare a wire stand by forming a loop in one end large enough to admit a 6-32 machine screw. The loop may be bent easily by inserting an 8-penny nail and putting the end of the wire in a bench vise and bending the wire to suit. Flatten the loop in the vise, after trimming off excess wire with side-cutting pliers (Fig. 504).

Bend the wire stand in the form of an L, and make the bend 2 inches from the loop. You will need a 6-32 x 1 inch machine screw, a pair of hex nuts and a knurled nut (binding post No. 1) as hardware for the loop.

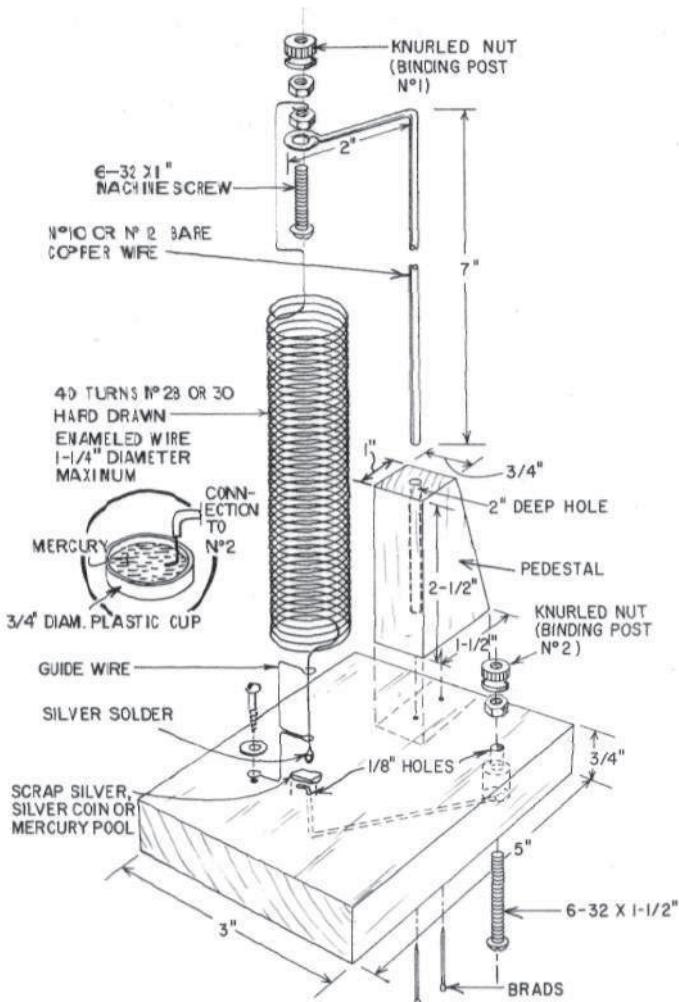


Fig. 502. A $2\frac{1}{2}$ -inch high pedestal (shaped as shown) is attached to the base as a stand for a 9-inch piece of copper wire-to support the spiral.

parts list for Roget's spiral

Wire: 15 feet of No. 28 or 30 hard-drawn brass or bronze; 10 inches of No. 10 or 12 bare copper; 1 inch of silver (for tip of spiral).

Hardware: 1—6-32 x 1" brass machine screw; 3—6-32 brass nuts, and 1—6-32 brass washer; large iron nail; knurled nuts; 2—knurled nuts; 1½ inch brads; 1—6-32 x ½ inch wood screw; 1—6-32 x 1½

Roget's spiral

inch machine screw.

Miscellaneous: wooden base, $3 \times 5 \times \frac{3}{4}$ " mahogany; wooden pedestal; 2 plastic pill-bottle caps; 1 oz. mercury (obtainable from drugstore or local dentist); silver coin or silver sheet (as substitute for mercury pool); 12" length of $\frac{3}{4}$ " wooden dowel; rubber band; paper strips (for height gauges).

Bore a hole vertically in the wooden pedestal slightly smaller than the wire size. The hole should be at least 2 inches deep, so that the L-shaped stand may be inserted and gently moved up or down to the correct height for the spiral.

Wind 40 turns of No. 28 or 30 hard-drawn brass or phosphor-bronze enameled wire (hard-drawn copper will do, if nothing else is available) on a short length of 3/8- to 3/4-inch wooden dowel (a 12-inch length will do). Keep the turns even on the dowel and as taut as possible. If hard-drawn brass or bronze is used, the dowel will have to be small, as the wire will unwind to a much larger diameter when tension is relaxed.

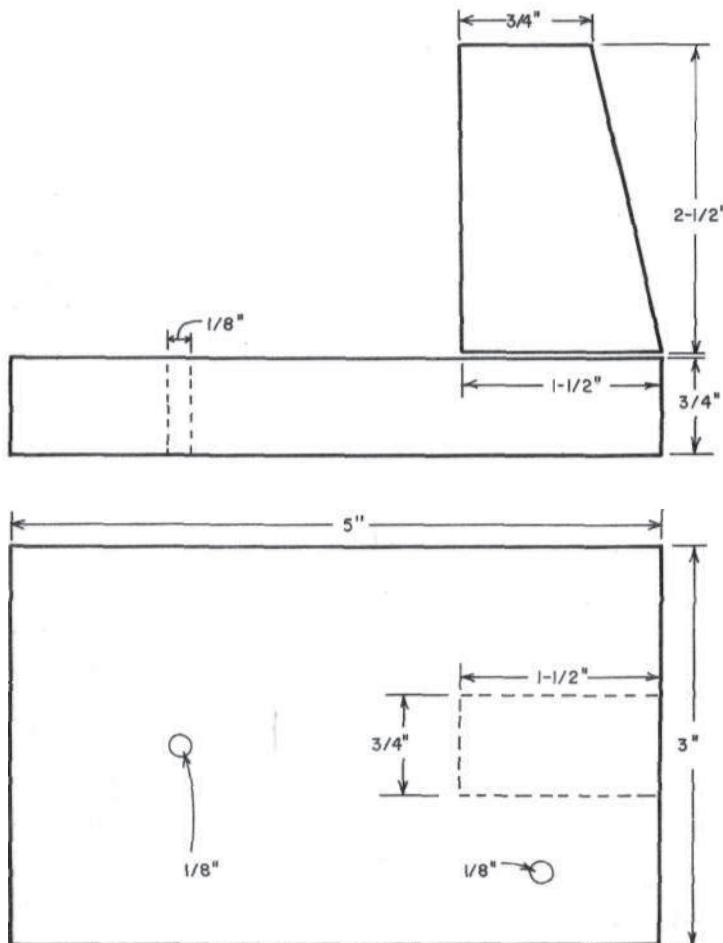


Fig. 503. Dimensions of the base and pedestal of the spiral.

If the wire is ordinary insulated copper, the dowel may be as large as 1-inch in diameter. In either case, the resultant spiral should be not more than 1½ inches in diameter and, when suspended on the bracket, be just long enough for its downward

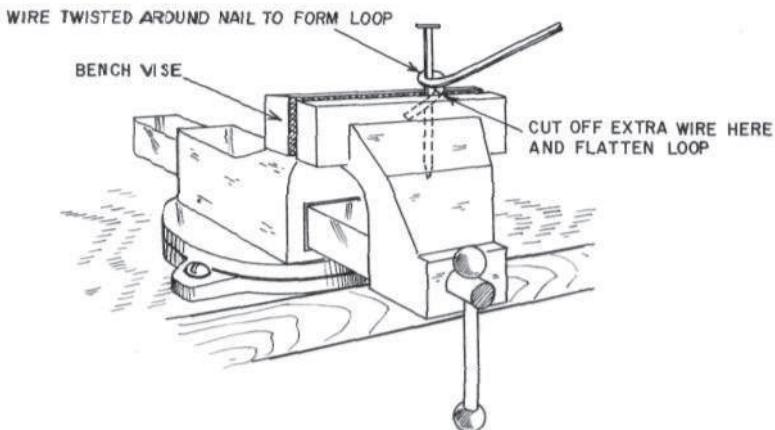


Fig. 504. *The loop for the wire stand can be easily formed. Insert an 8-penny nail together with the end of the wire in a bench vise and bend the wire to the shape desired.*

extremity to touch the base when the L-bracket is inserted as far as possible in the hole of the wooden pedestal.

Solder a bit of pure silver wire onto the downward tip of the spiral or, still better, wind a bit of the silver wire over the copper wire and crimp with pliers, leaving ½ inch of the silver wire extending downward to contact the mercury pool.

Bore a small hole through the base directly under the hanging spiral, thread a copper wire through it and wrap the wire tightly around the machine screw using binding post No. 2 on the base.

Secure the plastic top or cap of a 3/4-inch diameter pill bottle and cement it to the base directly over the hole. Force the sharp point of a scriber through the pill-bottle top, and draw the wire from binding post No. 2 through it. Scrape off the insulation (if enamel) and coil the end of the wire in the bottom of the pill-bottle top.

Fill the hollow top (now used as a cup) half full of mercury (or enough to cover the copper wire). If mercury cannot be obtained, cement a dime to the base and solder to it the wire from binding post No. 2.

Secure a second pill-bottle top to cover the mercury pool, to prevent spilling when the spiral is not in use. The cap also will help to keep the mercury clean.

"You are now ready to try the spiral. Connect one wire to binding post No. 1 and another to binding post No. 2. The other ends of these wires should go to a 1½ volt dry cell. The wire can be any convenient lengths of No. 18 or No. 20 insulated wire, stripped at the ends so that good connections can be made.

Warning! Mercury is a deadly poison. Keep your fingers away from it. Make sure the mercury is always kept out of the reach of small children. If you build projects as a team, be certain that every member of the group is aware of the danger.

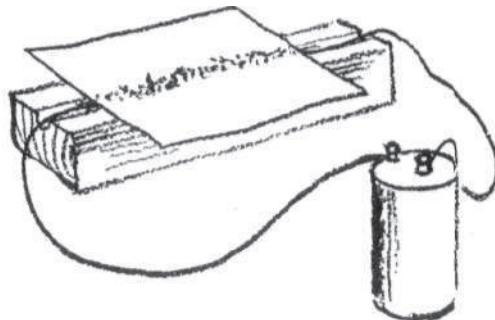


Fig. 505. Sprinkle iron filings on a sheet of stiff white paper held over a block of wood. The filings will arrange themselves in circles when current from a dry cell is passed through a wire underneath the paper.

Experiments to try

Experiment 1

To prove the existence of circular magnetic lines of force about a wire carrying current from a dry cell, drill a small hole vertically through a block of wood, insert the wire therein, and sprinkle iron filings on the block. The filings will arrange themselves about the wire in concentric circles. A sheet of stiff white paper on top of, and attached to the wooden block will make the circular arrangement of filings easier to observe (Fig. 505). Since the wire is a short circuit across the battery, make a temporary connection only. Do this by attaching a lead to the center or positive terminal of a No. 6 dry cell. Keep tapping the negative terminal on the edge of the battery with the other lead. Repeat until the filings form a pattern.

Experiment 2

Set the Roget spiral in operation, then carefully lower a rod of soft iron or a large nail within the coils. Note that the presence of the iron core produces a much more vigorous jumping action.

Why? Being an excellent conductor of magnetic lines of force, the iron core becomes in electromagnet when the contact is made in the mercury pool, but loses most of its power when the spiral rises and the contact is broken.

The presence of the iron core vastly improves the effect of the coil, often as much as several hundred times over a coil of wire without a core. Incidentally, all wires — both straight or coiled — exhibit a rather unusual phenomenon known as *induct-*

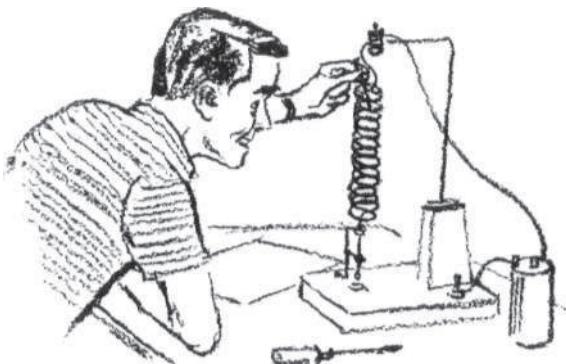


Fig. 506. Lowering a rod of soft iron or a large nail within the coil vastly improves the effect of the coil. The spiral bobs up and down vigorously because of the increased magnetic lines of force between the turns of wire.

ance which is said to exist whether an electric current is flowing in them or not. The presence of iron, however, causes this characteristic to be greatly magnified, especially when a current changes or varies rapidly in a coil. The Roget spiral bobs up and down more vigorously because there is an increase in the magnetic attraction between the turns of wire (Fig. 506).

Experiment 3

Attach a paper pointer to a nail and lower the nail into the spiral with a thin rubber band. Affix an indicator alongside the spiral to mark the position or height of the nail before the current is turned on. Note how the nail jumps and is drawn down into the spiral through the action of electromagnetic *suction*. Now try the same experiment using several nails tied together with thread.

Experiment 4

Tie some thread around a brass machine screw and lower the screw into the spiral. Note that the screw has no effect on the

action of the spiral. Try the same experiment with a bit of scrap copper. You will see that the copper, just like the brass, does not change the movement of the spiral.

Iron and steel inserted in the spiral will increase the magnetic strength of the spiral. Brass and copper will not.

Experiment 5

When the spiral is in action, bring a small compass close to the turns of the coil. You will see the needle of the compass swing vigorously even though the compass will be an inch or more away from the coil. With the help of the compass you can determine just how far away from the coil its magnetic field extends.

Put the compass on a small support, such as a scrap piece of wood, near the spiral. Observe the maximum swing of the compass needle as the spiral bobs up and down. You will be able to see this easily since the compass is divided into sections with clearly marked lines. Now tie some thread around a few iron nails and lower the nails into the spiral. Note that the pointer of the compass will now swing through a greater distance. Repeat this experiment with various other metals such as tin, brass, copper, etc. In this way you will be able to learn the effect that different metals have on magnetic fields.

building a solenoid



THE solenoid or *suction* coil is an electrically energized coil or winding, one of many forms of the electromagnet. Usually, it is equipped with an iron plunger that can be drawn magneti-

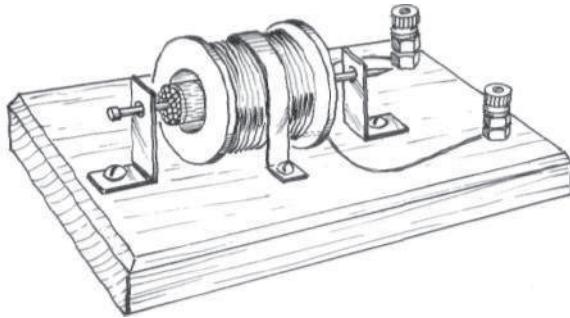


Fig. 601. A solenoid is a coil of wire. It becomes an electromagnet when we send a current of electricity through it.

cally into the winding, thus performing as a tripping or resetting mechanism for electrical circuit breakers, relays, track switches, valves and so on.

Complex electrical switchboards, electronic computers, elevators, telephone central offices, railroads, subways, battleships and large astronomical telescopes could hardly be operated at anything like present efficiency without this little device. Probably a billion or more solenoids are now in use in the electric and electronic industries. It has been estimated that a modern aircraft carrier has upward of 10,000, all vitally important in the business of firing

guns, raising planes to the flight deck, operation of communications and radar gear, and maneuvering the vessel at sea.

Actually, motor and generator field coils are a type of solenoid, but more generally the true solenoid is a simple coil of wire with a centrally located opening, into which an iron core may be drawn or pulled when an electric current is passed through the

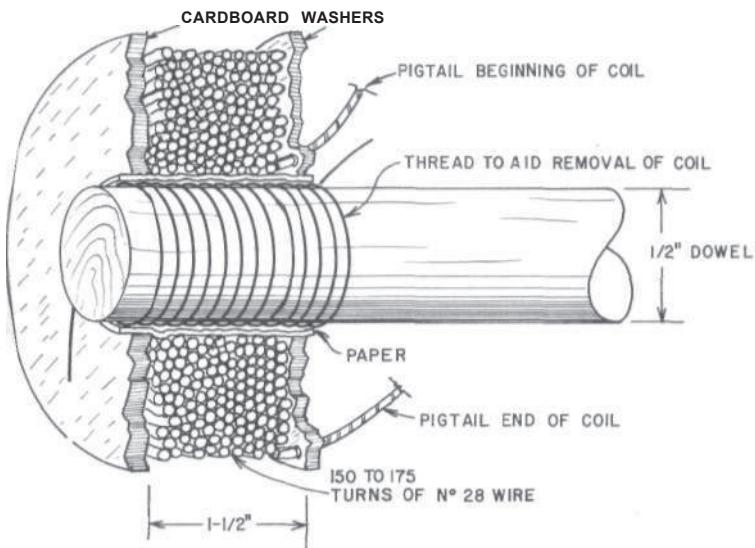


Fig. 602. Cutaway view of solenoid shows details of its construction.

winding. Solenoids or suction coils were among the earliest creations of those who laid the foundation of today's immense electrical industry nearly 150 years ago.

How it works

The laws of electricity and magnetism given to the world in 1864 by James Clerk Maxwell, as we learned earlier in the section on the galvanometer, may be summed up as follows: any two wires or coils tend to move so that the largest number of lines of force will be common to the two.

Thus, an iron core, if free to move, will enter the coil's opening where the density of the lines of force is greatest. An iron bar inserted in a helix, which is another name for a solenoid winding, is a much better conductor of the magnetic whirls within the coil than at either end, where the lines of force are somewhat dispersed. Hence, they are of less density. This is exactly the same as placing a ribbon in front of an electric fan. In the center of the stream

of air the ribbon is blown violently outward, while a bit to one side or the other the force of the air is less.

Since the strength or attractive force of the solenoid is much greater at the center of the winding, the iron core attempts to place itself in that position, where it can engage the greatest number of lines, though the magnetizing current remains unchanged.

Though somewhat weaker, a solenoid without an iron core obeys the same laws of magnetism. It is interesting to note that when the turns of wire are widely spaced, the pulling power is less than when the turns are placed close together.

A sketch of the solenoid is shown in Fig. 601.

Building procedure

Wind about 20 turns of heavy thread on a 3-inch piece of $\frac{1}{2}$ -inch diameter wooden dowel and cement down the ends. Wind several layers of heavy paper over the thread, cementing the final

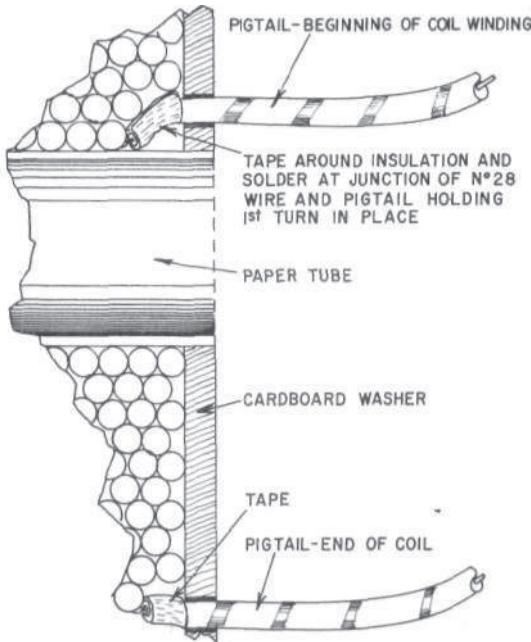


Fig. 603. The pigtail wire is soldered to the beginning of some No. 28 enameled copper wire and about 150 to 175 turns of copper wire are wound evenly with the washers.

turn along its end. The paper can be held in place with a rubber band after cementing. See Fig. 602.

Cut two 1½-inch washers from heavy cardboard or pressed board, fit one over each end of the paper and cement so that the washers are 1½ inches apart. Allow the cement to dry thoroughly.

Punch a small hole near the bottom of one of the washers and insert one end of a 3-inch piece of flexible pigtail wire through it. This will be the beginning terminal of the solenoid to be wound within the 1½-inch coil form.

Solder the pigtail wire to the beginning of some No. 28 enameled copper wire and wind about 150 to 175 turns of the copper wire evenly with the washers. Insulate the joint as shown in Fig. 603 and fix the pigtail in place. Cement each layer as it is finished.

Pierce one of the washers at the level of the final layer of the winding. Insert another pigtail, solder to the winding and insulate

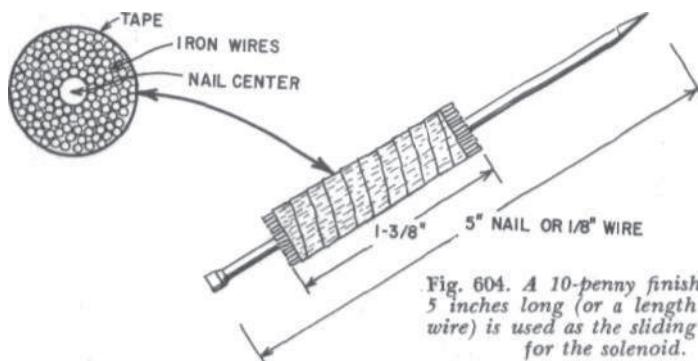


Fig. 604. A 10-penny finishing nail 5 inches long (or a length of iron wire) is used as the sliding support for the solenoid.

again, fixing the final few turns as in Fig. 603. Coat with Duco cement and allow an hour for thorough drying.

Pull out the 20 turns of thread around the dowel and slide off the coil. Cement the inside of the hole through the winding with more Duco and smooth with the dowel, which can be easily inserted now.

Mount on a 3 x 6-inch base, attach the terminals of the solenoid to the binding posts, and the winding job is completed.

Since no solenoid is quite complete without a soft-iron core or plunger to illustrate the remarkable suction power of the device, secure 25 or so soft iron wires, the kind that florists use to strengthen the stems of flowers and plants (the cost is small). Cut the wires into 1 3/8-inch lengths, trimming off the excess length of the final section.

Anneal a 10-penny finishing nail in a gas flame over the kitchen

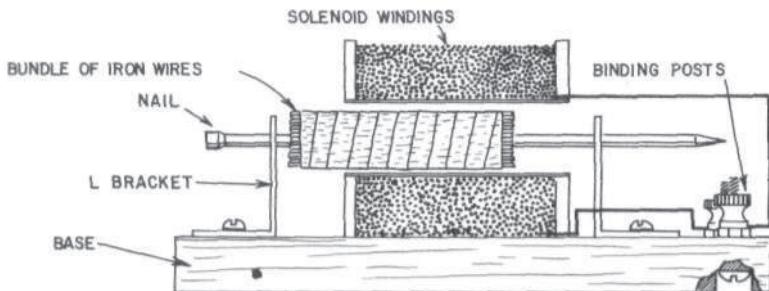


Fig. 605. Arrangement of the sliding mechanism. The bundle of wires should be mounted so that it moves freely within the winding.

stove until red hot, then allow to cool slowly. Hold one end in a pair of pliers while heating, then reverse and heat the other end. A 4- or 5-inch length of iron wire may be used instead of the nail.

Bind the nail in the exact center of a 3/8-inch diameter bundle of iron wires, finally cementing with Duco and taping all over with black plastic tape (Fig. 604).

Mount the bundle of wires (or core) so that it moves freely within the solenoid. Fig. 605 shows the arrangement of the sliding mechanism.

parts list for solenoid

Wire-. 1½-lb. spool of No. 28 enameled copper wire; 25 pieces of 12" soft-iron wire (obtainable at a florist or garden shop); 2—6" pieces of flexible pushback wire.

Hardware: 2—6-32 x 1" brass machine screws; 6-32 brass nuts, and 2—washers for binding-post assemblies; 2—1" length L-type brass brackets; 2—%"

roundhead woodscrews; 2—knurled nuts; 1_10-penny finishing nail, or 5" length of soft iron wire $\frac{1}{8}$ " in diameter.

Miscellaneous: several yards of heavy thread; 3" piece of $\frac{1}{2}$ " dowel rod; .1—3 x 6" base finished with varnish; 2—paper washers 1½" in diameter, or 2—2" squares of pressed board (with 9/16" holes in center).

Experiments to try

Experiment 1

Attach a spring balance to the core or plunger of the solenoid as shown in Fig. 606 and measure the magnetic attraction. Observe that, when one dry cell is connected to the binding posts, the attraction is much less than when two dry cells in series are used. Why? The answer is this: one cell (1.5 volts) forces only half as much current through the winding as two cells (3 volts). Therefore, the current through the coil is twice as much when two cells are employed, since the resistance (ohms) of the coil remains the same.

We could, of course, measure the resistance of the winding with

an ohmmeter. Assuming, however, that we have no such instrument, we can calculate the resistance as follows: By measurement, the average length of one turn is about 4 inches, and since there are 175 turns in the bobbin, the whole length of the No. 28 Mire would be about 58 feet. Applying this to a wire resistance table,

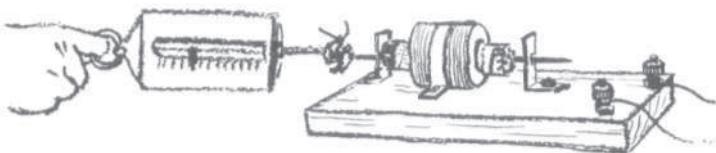


Fig. 606. *To measure the magnetic attraction of a solenoid, attach a spring balance to the core or plunger.*

we find the indicated resistance of the solenoid to be about 3.5 ohms, since 1,000 feet of No. 28 copper (soft-drawn) is 65 ohms at a temperature of 68°F.

By drawing a curve of how much pull the plunger registers, in ounces, on the spring balance for each condition, we find the changing electromagnetic attraction. This is almost the exact method employed by experimental engineers in determining the magnetic force required to do certain mechanical jobs.

Note that, as the plunger nears the center of the coil, the greater is the attraction in ounces, until the plunger reaches the coil's *magnetic center*, at which point the plunger comes to rest. This geometrical center of coil and plunger is the point where the magnetic lines of force are most concentrated. Note that when the plunger is pushed either way beyond the magnetic center, it tends to return to the center.

Experiment 2

Remove the centering brackets from the solenoid. Move the plunger toward one end or the other. Apply the current quickly by flicking one of the battery wires across the binding post from which it has been disconnected. If this is done rapidly enough, the core will be ejected from the solenoid winding, somewhat like a projectile fired from a gun barrel. Move the core to the other end of the coil and note that the ejection takes place as readily from one end as the other.

Obviously, if the battery wire is held on the binding post, the core will shuttle back and forth and come to rest in the solenoid's magnetic center.

Experiment 3

Place two iron rods inside the solenoid opening after the bundle of wires has been removed. "When the battery is connected, the rods jump apart, indicating that iron objects similarly magnetized repel each other.

Experiment 4

Wind a few turns of fine insulated copper wire on a $\frac{3}{4}$ -inch dowel and cement the turns to keep them from unwinding. Connect the small winding *in series* with the solenoid winding. Suspend the small winding on a thread so it turns freely near one end of the solenoid. When the two coils are connected to a dry cell, the small coil turns on the thread until both winding are *concentric*. This simply means that the two coils will be aligned just as though they had a common center.

These movements are the result of magnetic attraction and repulsion, (repulsion in the case of the iron wires), and the *magnetic concentricity* of Maxwell, in the case of the coils. These magnetic forces have been applied in many electrical measuring instruments to move pointers that indicate voltage, amperes, watts, ohms and so on.

Experiment 5

Magnetic circuits have resistance almost exactly the same as electrical circuits. Make a magnetic circuit for the solenoid by bending a $\frac{1}{4}$ -inch bundle of wires in the shape of a U, and passing one leg of the U through the solenoid. Procure a piece' of soft-iron bar to unite the ends of the U, thus forming a *closed* magnetic circuit. Try the magnetic attraction of this *keeper* when a dry cell is connected to the solenoid winding, and note that it is far more powerful than that of a straight bundle of iron wires.

Experiment 6

Plunge the ends of the U-magnet thus formed into a receptacle of iron filings, leaving the keeper (soft-iron bar) attached. Note that very few filings attach themselves to the ends of the U. This is because the magnetic lines have an excellent pathway through the iron wires and the keeper. In other words, the resistance of the iron core is at its lowest.

Experiment 7

Place a piece of cardboard between one of the U poles and the keeper, forming a *magnetic gap*. Note that a great number of filings cling to the two poles around the cardboard, because the magnetic lines must pass around the paper spacer to complete the magnetic circuit. However, the magnetic gap thus created has a

strong magnetic *leakage*, which reduces the flux density of the whole core. Hence, the core has a higher magnetic resistance.

Experiment 8

An iron-clad electromagnet for lifting large steel and iron objects, pig iron, steel rails, etc., has a very powerful force when such material comes into actual contact with its concentric polar surfaces, but is relatively weak, when the material to be lifted magnetically is a few inches away. Test the lifting power of the solenoid by removing the keeper of the U magnet, attaching one or two dry cells across the terminals of the solenoid, and passing it over the steel tools on your workbench.

Experiment 9

In this experiment we are going to ask you to construct a lamp dimmer (using a 15-watt light bulb) if you have not already built the one described earlier on page 57. Obtain a porcelain lamp base and a line cord (sold in electrical supply stores). You can get this with a plug mounted on one end. Somewhere near the center



Fig. 607. *A lamp dimmer is constructed by connecting a 15-watt 117-volt electric light in series with a solenoid. Withdraw the plunger in the solenoid, the lamp glows; insert it, the lamp gets dimmer.*

of the lamp cord pull the two wires apart. Now cut one of them and strip the ends for a length of about one inch. Connect these stripped ends to the terminals on the lamp base. Insert the lamp.

The two free ends of both wires of the lamp cord can now be connected to the binding posts of the solenoid shown in Fig. 605.

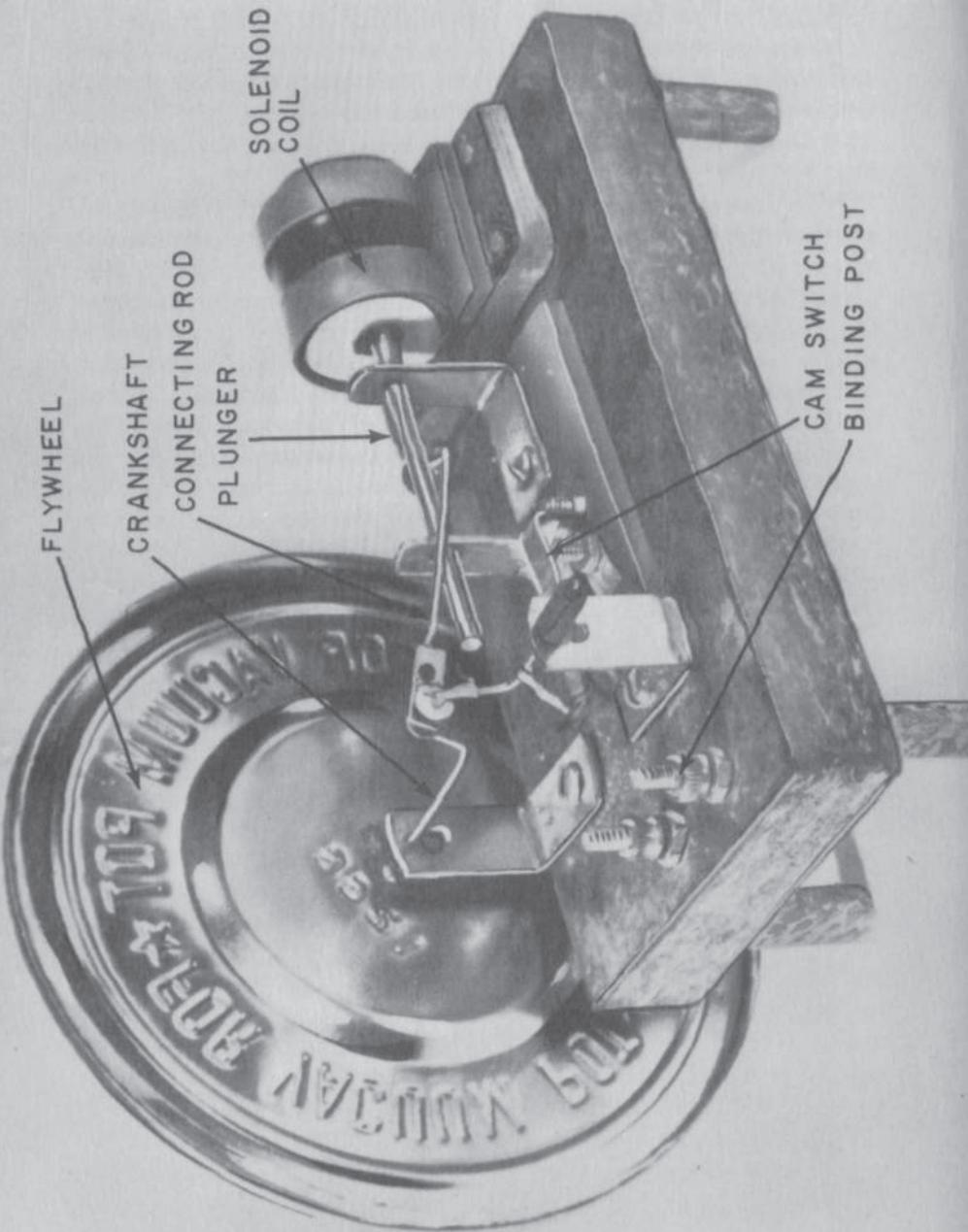
Because we are so accustomed to having power outlets in our home, we may forget that the line voltage can be dangerous. Do not put the plug into the outlet until you are sure that all

connections have been made and that the lamp is in its socket. (Be sure to remove the plug from the outlet before touching terminals on the lamp or the solenoid's binding posts.)

When you have checked all of your work, insert the plug into the outlet. The lamp should glow. Note that, with the plunger withdrawn from the solenoid, the lamp glows at its brightest, but with the plunger fully inserted, the lamp is dimly lighted. (See Fig. 607.)

Why? Let us explain by saying that all coils and wires exhibit a rather mysterious phenomenon called inductance, a tendency to oppose any change in the current flowing through them. This property is due to the voltages induced by the changing magnetic field. When iron is present, as in the plunger, this inductance is greatly magnified. As the alternating current rises, a voltage known as a counter-voltage, or counter-emf, also rises but appears across the coil or wire in the opposite direction. This voltage retards the flow of the ac from the light socket when the plunger is in place — hence, the lamp becomes dimmer. When the plunger is withdrawn, the retarding effect is smaller and the lamp becomes brighter.

Strangest of all, however, is that this counter-emf completely reverses itself as the alternating current drops to zero. What actually happens is that, as the current falls, it causes the magnetic field in the circuit to collapse. But as this happens, the induced emf starts the induced current flowing in such a direction as to build up a magnetic field that assists the original magnetic field, and thus tends to prevent its collapse. This effect tends to even out, smooth or choke rapid alternations or pulsations of current, and is most pronounced when the inductance is greatest.





building a solenoid magnetic engine

AN engine is a mechanism designed to change or convert the reciprocating action of a piston into the rotating action of a wheel. Many and varied have been the creations of the past century to solve such problems with the highest efficiency of mechanical translation. The steam railroad engine and the internal-combustion gasoline motor of the automobile are, perhaps, the most outstanding and familiar examples of this never-ending quest for machines to change cylinder pressure into torque.

However, a new kind of pressure had been discovered — the pressure of voltage in a wire — which applies the power of magnetism to produce turning power, as in the electric motor. Nevertheless, the reciprocating steam engine with its exposed piston rods, cranks and wheels was a phenomenon to behold as America's iron horse ponderously but glamorously rode the rails from ocean to ocean.

In electricity, however, some of this bygone glamour may be recaptured by the solenoid engine described in this chapter, which illustrates every basic function of the great railroad locomotive except that of steam pressure generated in a boiler (Fig. 701).

In the preceding chapter you learned about the suction power of a solenoid winding. The magnetic engine utilizes this power to attract a plunger piston, turn a crankshaft and with it an attached flywheel. This action is timed with a cam-operated electric switch,



Fig. 701. Solenoid magnetic engine. The switching action is completely automatic.

COFFEE-CAN LID FLYWHEEL.

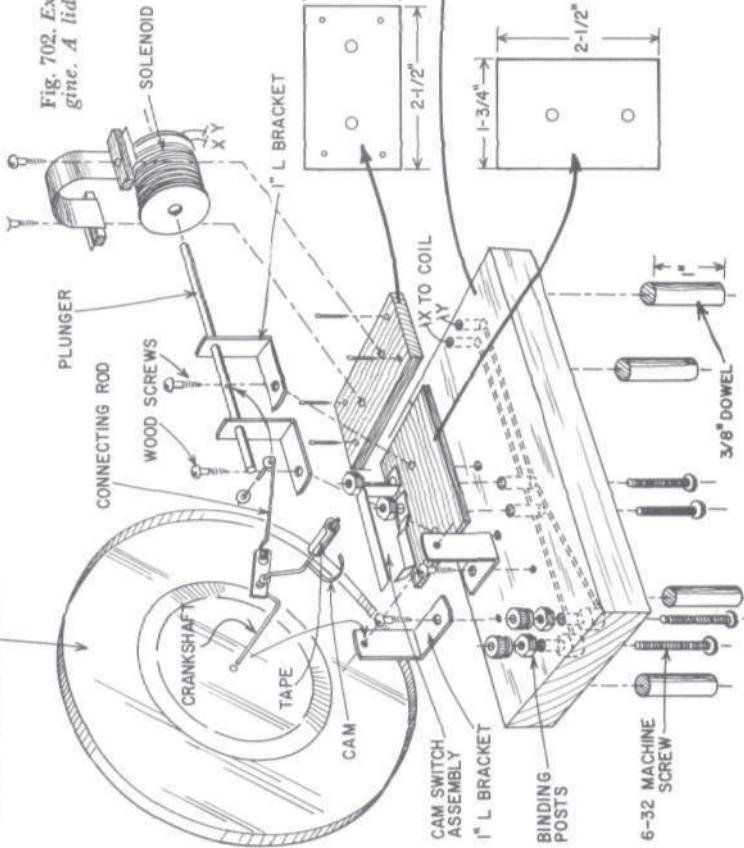
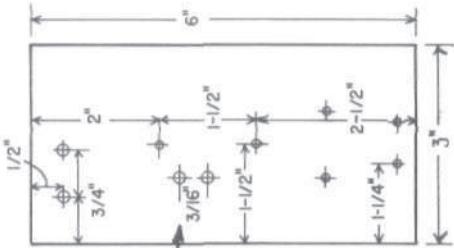


Fig. 702. Exploded view of the solenoid engine. A lid from a coffee can is used for the flywheel.



which makes and breaks the electric circuit every half-cycle of rotation.

Thus, the solenoid pulls or attracts the piston for a half-turn, then releases the piston automatically as the circuit is broken by the cam-operated switch, and so OIL. The flywheel receives and stores rotational power for a half-cycle, then feeds it back to carry on the action until the next cycle of events happens.

The flywheel of a steam or gasoline engine acts in the same way except that in the solenoid engine the magnetic power is suction,

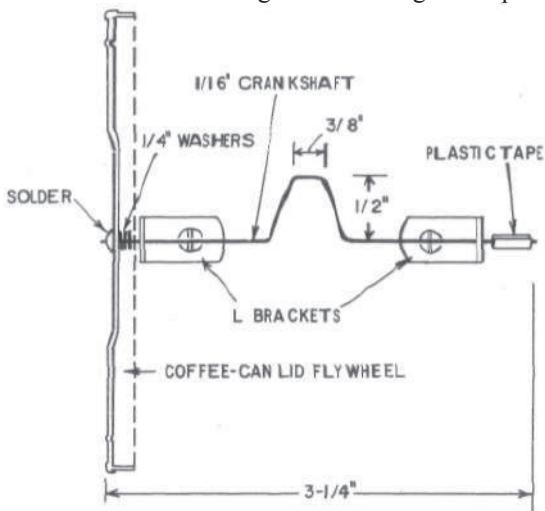


Fig. 703. A small hole is punched in the exact center of the coffee-can lid flywheel. To mount the flywheel, one end of the crankshaft is slipped through the hole and soldered.

whereas in the steam or gasoline engine the power is delivered to a piston head by pressure within a cylinder.

Although not a very powerful device, the solenoid engine described in this chapter might be made more powerful by adding more solenoids. Four, for instance, might be fitted with independ-

parts list for solenoid magnetic engine

Wire: 12" length of hookup wire; 2—large paper clips (for crankshaft and connecting rod); 1—solenoid winding (see the preceding chapter for construction details).

Hardware: 1—10-penny nail (see text); 2— $\frac{1}{2}$ " round-head woodscrews, bright finish; 2—6-32 x 1" machine screws and 2—6-32 nuts (for mounting switch to

base) 2—binding-post assemblies (6-32 or 8-32 screws and nuts); 3—small pieces of thin brass or copper sheeting (for switch and cam); 4—1" brass L-brackets.

Miscellaneous: 1—3 x 6" wooden base; 1—vacuum-pack coffee-can lid (for flywheel); 4—1" pieces of 3/8" dowels (for legs).

ent cam switches and connecting rods and linked with a single four-position crankshaft and flywheel. The home experimenter should find great interest in constructing such a machine. It would not need a starting push to set it in operation, since at least one of the solenoids would always be in electrical contact, ready to deliver instant power to the multiple-position crankshaft.

Building procedure

Prepare a 3 x 6-inch base and fit it with 1-inch high legs made of short pieces of 3/8-inch dowels. Finish with varnish.

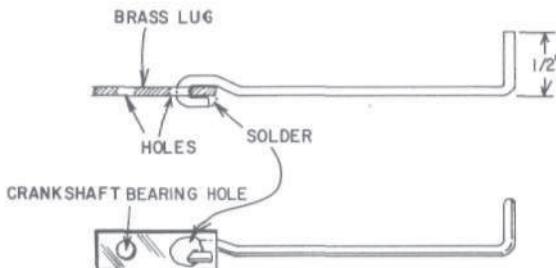


Fig. 704. A 2½-inch piece of 1/16-inch wire is bent in the shape shown, forming a connecting rod to link the crankshaft with the plunger.

Mount the solenoid of the preceding chapter near one end of the base's center line and bind with two strips of ½-inch plastic tape. The two ends of each strip of tape may be held under a 1/8-inch pressed-board cleat screwed to the base. Note that, when the solenoid is fixed to the base, the center of its cylindrical opening will be about ¾-inch above the surface of the base (Fig. 702).

Anneal a 3¼-inch nail (a 10-penny nail). Cut the head off with

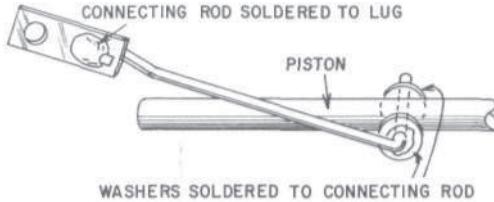


Fig. 705. Bend one end of the connecting rod and insert it through the pistol hole previously drilled. Washers soldered to the connecting rod will keep it in position.

a hacksaw. Bore a 1/16-inch hole through the nail exactly 1-3/8-inches from one end. This will be the piston rod or plunger of the solenoid winding.

Mount two 1-inch L-brackets in line with the opening in the solenoid, the first $\frac{1}{4}$ -inch from the solenoid's end and the second 1-3/8-inches from the first. The 1/8-inch holes in the vertical legs of

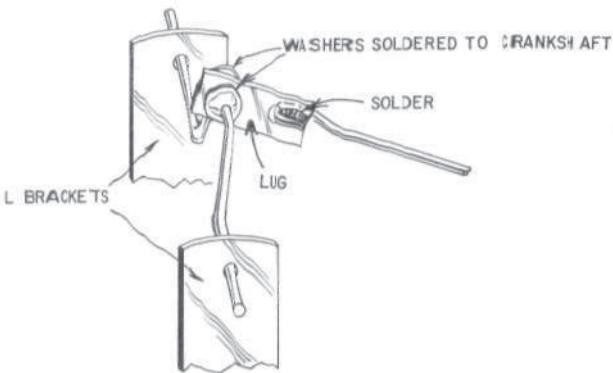


Fig. 706. Brass or copper washers are soldered on each side of the connecting-rod lug to prevent it from wobbling and binding on the crankshaft.

the two brackets will serve as guides for the nail plunger, which will move in and out of the solenoid like the piston rod of a steam cylinder.

Mount two more 1-inch L-brackets exactly 3-inches from the face of the solenoid, measured to the center line of the brackets.

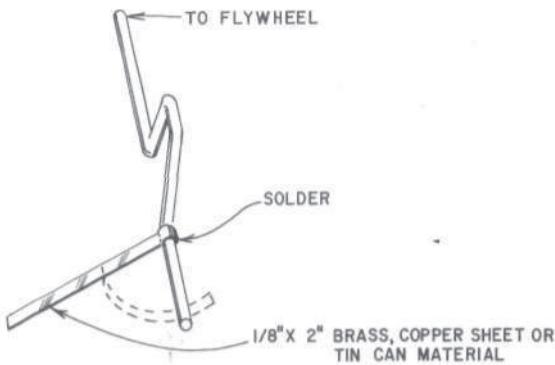


Fig. 707. A loop is formed at one end of a strip of copper or brass sheeting and soldered to the crankshaft.

The brackets should be positioned so that the center line forms a right angle to the center line of the guides for the nail plunger (Fig. 702).

Bore a 1/16-inch bearing hole in each bracket at the same height from the base as the solenoid plunger. Through these holes will finally go the crankshaft, to be bent from a large straightened paper clip, as in Fig. 703 (a 414-inch length of 1/16-inch straight wire may be used instead of the paper clip). Now enlarge the 1/16-inch bearing hole slightly so that the crankshaft wire may be inserted without binding.

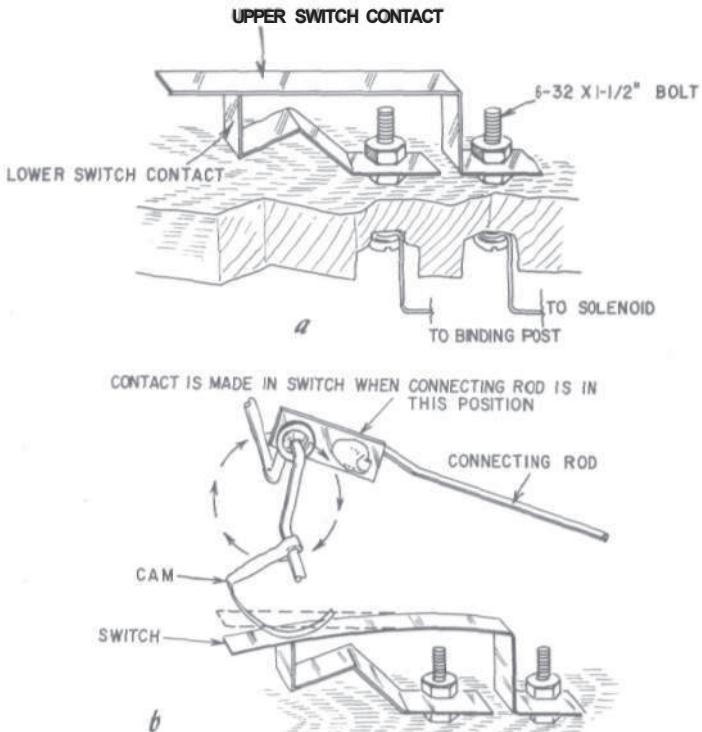


Fig. 708. Two strips of copper or brass sheeting (a) are cut and bent to the shape shown to form the rotational contactors (switch). When the crankshaft, connecting rod and piston (b) are in correct position to be drawn into the solenoid opening, the switch energizes the solenoid.

Secure the lid of a vacuum-packed coffee can and punch a small hole in its exact center. Solder one end of the crankshaft in this hole, thus mounting the flywheel.

Bend a 2½-inch piece of 1/16-inch wire in the shape shown in Fig. 704, forming a connecting rod to link the crankshaft and pivot hole bored in the nail plunger. A flat piece of brass may be soldered to the crankshaft end of the connecting rod (Fig. 705). Bore a 1/16-inch hole through the brass lug (enlarging it with the

tang end of a small file, pass the connecting rod through it and solder it.

Pass the other end of the connecting rod through the 1/16-inch hole in the nail plunger. Solder small brass or copper washers on each side to hold the bent end (L-shaped) of the connecting rod.

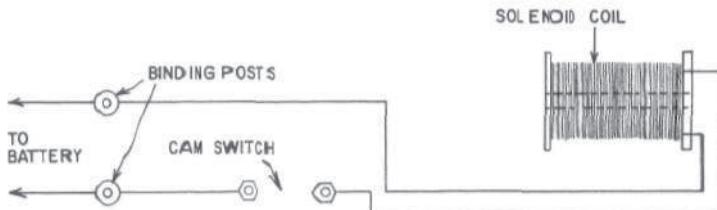


Fig. 709. Make the connections to the binding posts and the solenoid as shown here.

in position through the hole in the nail plunger. Finally, solder washers on both sides of the connecting-rod lug to prevent it from wobbling and binding on the crankshaft (Fig. 706).

Cut a strip of copper or brass sheeting 1/8-inch wide and 2-inches long and form a loop at one end (this can be done by bending it around another wire). Solder firmly to the crankshaft (Fig. 707) just inside of the L-bracket farthest from the flywheel (this strip will finally be bent into a semicircular form to make a cam).

Cut two $\frac{1}{4} \times 2\frac{1}{4}$ -inch strips from the same material and bend to the shapes shown in Fig. 708. Drill 1/8-inch holes through one end of each strip and mount under 6-32 nuts on a bolt going through the base. These strips will form the rotational contactors (or switch) to energize the solenoid when the crankshaft, connecting rod and piston are in the correct position to be drawn into the solenoid opening.

Mount two binding posts as shown in Fig. 702.

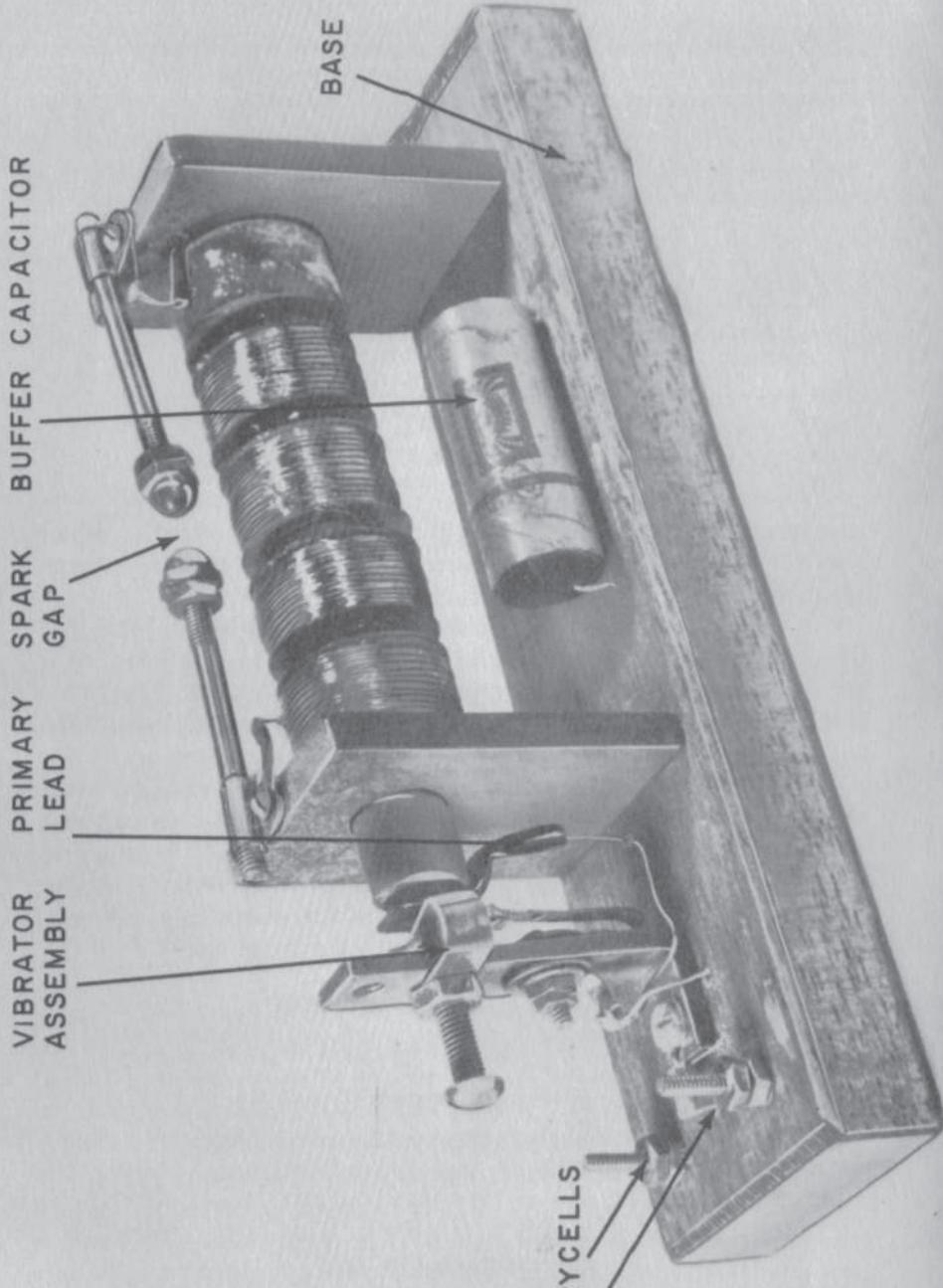
Wire the solenoid, cam switch and binding posts as shown in Fig. 709.

Bend the cam strip so it presses the switch blades together once each rotation as the crankshaft approaches the *up* position (delivering current to the solenoid) and breaks the circuit when the crankshaft is down.

Experiments to try

Experiment 1

Attach a small grooved pulley to the crankshaft to provide power for simple workbench toys.



building a spark coil



MICHAEL FARADAY, giant of electrical experimentation, made so many discoveries in the early nineteenth century that it is difficult to find an electrical device today that is not related to one or another of his now famous lectures at the Royal Society in London.

Likewise, the work of Joseph Henry left a rich legacy of theory and experimental fact that not only startled his students at the College of New Jersey (now Princeton University) and amazed the villagers of the college town, but established the basis of one of the most extensive applications of electricity—*electromagnetic induction*.

Mutual induction

Faraday is credited with the discovery of *mutual induction*; Henry with that of *self induction*. Mutual induction is the operating principle which explains how electrical energy is transferred from one winding (the primary) of a coil to the other and appears across the secondary winding of a coil as a higher or lower voltage (depending upon whether the device is a *stepup* or *stepdown* transformer).

Self induction is the operating principle where only one coil of wire is concerned. This will be explained later on.



Fig. 801. *The completed spark coil. With the help of a vibrator and a transformer, the low voltage of a few dry cells is stepped up to a very high voltage.*

The Ruhmkorff coil

Mutual induction is the principle of the spark coil, known as the Ruhmkorff coil. With it the German scientist did so much unusual experimental work that the device eventually was named for him.

Heinrich Daniel Ruhmkorff was a physicist who specialized in the creation of precision galvanometers and similar instruments. One of his largest coils was made in 1867. It had a secondary -winding of fine wire (about 62 miles of it!) that produced a spark 16-inches long.

Nine years later an experimenter built a sparking-coil secondary that produced a 42-inch spark. It contained some 280 miles of wire wound in the form of a long bobbin on an insulating tube. There were nearly 342,000 turns, which produced a secondary potential of about 3,000,000 volts.

The basic spark coil

Essentially, a spark coil consists of two windings. The first is usually wound on a core of iron wires and fitted with an interrupter (like a doorbell) to make and break the primary voltage and current. The faster this is done, the more voltage is induced into the secondary winding by the rapidly rising and falling magnetic lines of force in the core. The second winding, or secondary, is generally wound in bobbins over an insulating tube and placed over the primary. A small capacitor is connected across the interrupter contacts to absorb the spark of the primary current, thus causing a more rapid break and a much higher secondary voltage. (The spark coil we will build is shown in Fig. 801.)

These are the essentials of the spark coil, which pumped life into wireless in the early days of Marconi's transmitter, filled the air with dots and dashes of thousands of American ham operators, and now is the basis of the ignition systems of millions of automobiles.

Alternating-current transformers

Incidentally, the very same principle — except for the high-voltage spark gap — is used in millions of ac stepdown transformers, by which American homes are provided with house lighting power. In 1856, S. A. Varley of London patented an induction coil in which the iron core was folded outside the two windings to complete the magnetic circuit. Thus was born the true alternating-current transformer, evolved from the original idea of the spark coil. The ac transformers seen on poles along roadways and streets are stepdown devices. They receive a higher voltage on their primary

windings (ordinarily about 2,300 to 2,400 volts), and supply 115 to 120 volts for home circuits.

When the voltage is stepped down, the current is raised in the same ratio. The opposite is true when a transformer steps the voltage up — the current is proportionately reduced. This is what

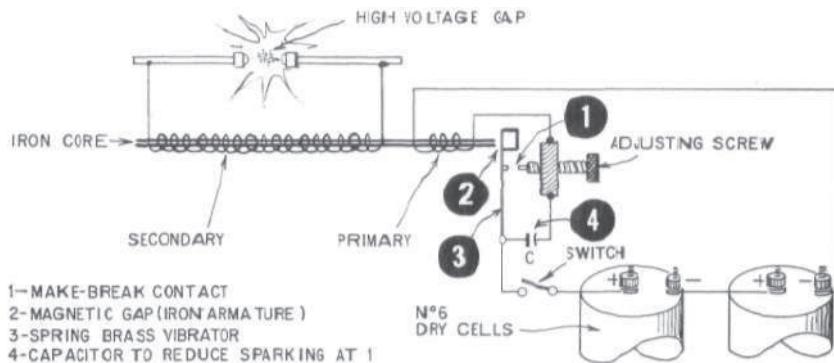


Fig. 802. *The spark-coil circuit. Before current can flow in the primary circuit, the adjusting screw must be turned until it barely touches the contact of the vibrator.*

happens in the spark, coil. As the vibrator or interrupter makes and breaks the primary circuit, it induces a very high voltage in the secondary winding, thus generating a series of sparks that pass through the air from one secondary terminal to the other.

The vibrator is a strip of spring brass or steel fitted at one end with a soft-iron armature and on its opposite end with a silver- or platinum-tipped adjustable screw and contact button (exactly like an electric doorbell).

How it works

Fig. 802 is a drawing showing the arrangement of the spark coil, with secondary, primary and vibrator.

When the switch is closed, current from the dry cells passes through the brass vibrator 3, the make and break contact 1, the adjusting screw and the primary winding, and then returns to the dry cells to complete the circuit. The magnetized core attracts the iron armature 2 and breaks the circuit which, in turn, demagnetizes the core by cutting off the current flowing from the cells. The released armature thus springs back to its original position and makes contact again.

This make-and-break cycle of events is repeated hundreds or thousands of times a minute as long as the switch is closed. This rapid magnetization and demagnetization of the core produces a

rapidly changing magnetic flux that reaches the many turns of fine wire in the secondary and *induces* in it a very high alternating voltage which jumps across the secondary spark gap. This is an example of the phenomenon of *mutual induction* between two coils.

Capacitor C absorbs (or suppresses) the spark at 1 when the iron armature is attracted toward the core as the switch is closed; thus causing the primary dry-cell current to fall rapidly to zero. This causes a much higher voltage in the secondary winding for the more rapidly the magnetic field collapses, the greater is the induced voltage. Time, therefore, is a vital element in the production of the secondary voltage of a spark coil.

Do not be too dismayed at this time at the seeming complexities of alternating-current phenomena. You will soon learn about Newton's laws of force and motion — that a body at rest tends to remain so, or, if in motion, tends to continue in the same direction with the same speed until it meets an opposing force. In other words, nature tends to preserve the status quo, resisting sudden departures from an established condition.

Counter-emf (electromotive force or voltage)

Self-induction of the primary-circuit coil has a similar and very important effect on the spark coil as a whole. When the switch is pressed, a *counter-emf* (opposition voltage) is generated that opposes the dry-cell current, thus preventing the magnetic field from rising rapidly in the core. At the break of the primary current, however, the opposite effect takes place. The self-induced current tends to prolong or increase the dry-cell current, hence the action is a less rapid fall to zero and sparking at 1. The capacitor minimizes this action and the primary current falls rapidly.

But this is not all that happens. At each *make* of the primary, an *inverse* or opposite current is induced in the secondary winding, while with each *break* of the primary, a *forward* current surge is induced in the secondary. Therefore, interrupted currents in the primary tend to produce alternating currents in the secondary. Thus, what flashes between the secondary brass balls is a high-voltage spark that alternately changes its direction with each cycle of the primary vibrator.

A little more about how capacitor C, wired across the spark gap, actually works to aid the spark coil's operation: When dry-cell current flows through the primary winding, the capacitor is dormant because it is short-circuited. At the break, however, the self-induced voltage of the primary coil charges the capacitor,

which releases its stored energy back through the primary and the dry cells in the *opposite* direction, to that of the charging current. This rapidly demagnetizes the core try tending to create a magnetic flux in the opposite direction.

Much more can be learned about the true action of the spark coil by consulting more advanced works on the topic, all of which will add to a better understanding of the generation and use of high voltages by transformers.

Building procedure

Secure a mica or hard-rubber tube 11/16-inch, outside diameter, with 1/16-inch walls (about 6-inches long).

Prepare a bundle of soft-iron wires (the kind supplied by florists for holding flowers erect). Cut them into 5½-inch lengths and bind with black plastic tape, end to end.

Wind one layer (80 turns) of No. 20 enameled wire directly over the tape. Center the winding on the soft-iron core, leaving about 1 foot of wire at each end of the winding for terminals. Bind with

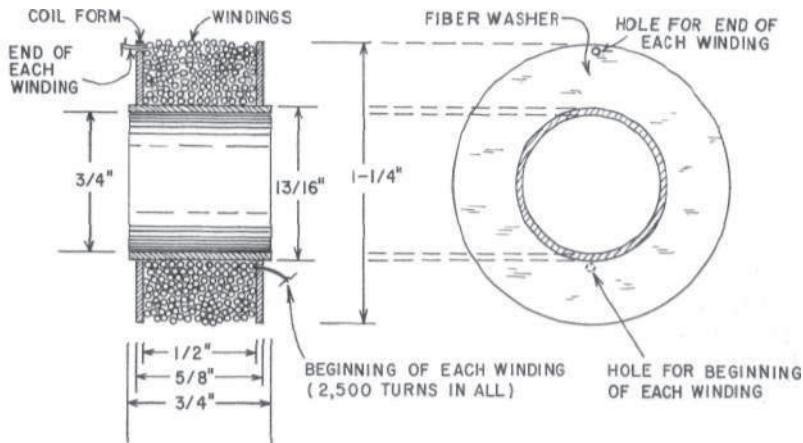


Fig. 803. Construction of one of the coils for the secondary winding. Each of these coils is known as a bobbin.

heavy thread to prevent the coil from unwinding. This will be the primary winding.

Force the primary and core inside of the mica or hard-rubber tube. If they won't go into the tube, pull out a few strands of the iron wire and squeeze the bundle tighter by twisting the primary more snugly on the core (it may be necessary to remove some of the plastic tape if the fit is too snug).

Prepare five bobbins of No. 37 to No. 38 enameled wire. Each

bobbin should have not less than 2,500 turns, and should be wound on an insulating spool made from a 6-inch length of 13/16-inch OD (outside diameter) filer tubing cut into $\frac{3}{4}$ -inch lengths. The ID (inside diameter) should be not less than $\frac{3}{4}$ -inch, so that the bobbins, when finished, "will slip snugly over the mica or hard-rubber tube of the primary.

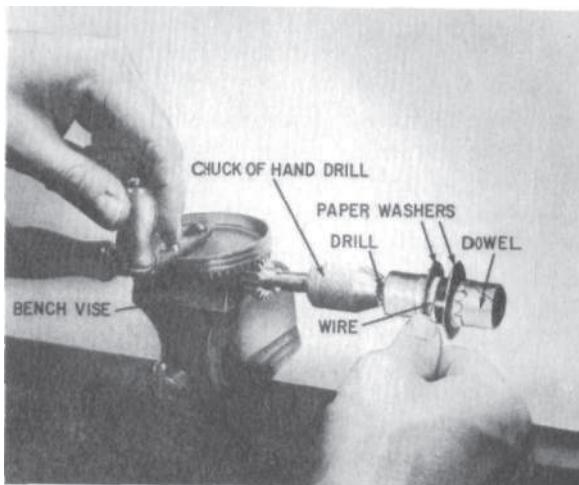


Fig. 804. With the help of a hand drill clamped in a bench vise, it isn't difficult to wind 2,500 turns of wire on each coil form.

Secure a dozen fiber washers, 13/16-inch ID, 1 1/8 to 1 $\frac{1}{4}$ -inch OD. Slip one washer over each end of one of the 34-inch tubings and cement in place with Duco (Fig. 803.)

Fit the completed coil forms over a wooden mandrel or dowel (Fig. 804).

Clamp a hand drill in a workbench vise, insert a steel drill bit and bore into the mandrel. A drop or two of cement where the drill enters the mandrel and another drop on each side of the coil form will fix it in place while the actual winding proceeds. It might be advisable to wind a few turns of thin thread on the mandrel before the coil form is forced over it. This can be pulled out later, thus freeing the finished windings so they may be withdrawn easily.

Place the spool of No. 37 or No. 38 enameled wire upright on the floor between the feet so that the wire will come off freely as you turn the handle of the drill and wind the 2,500 turns on the coil form. Gauge your winding this way: the crank of an ordinary hand drill turns once for five turns of the chuck. This means that

500 turns of the handle or crank, will wind 2,500 turns on the coil form. Turn the crank 100 times, then place a pencil mark on a sheet of paper, then wind 100 more and so on, until the winding is completed. Be sure, however, to turn the handle of the drill in the *same* direction for all five bobbins. This is very *important*. The result will be five coils all wound in the same direction, aiding each other in producing the high voltage expected of the secondary.

Cement every few turns of wire as they go on the coil forms, to prevent unwinding as the end is neared. You are already familiar with other winding methods, such as inserting the beginning of each coil through a hole at the bottom of one of the washers, and the end through another hole at the top. Obviously, it is important to *take your time*, since the secondary wire is very fine and difficult to handle.

As each coil is finished, dip the ends into a caustic solution (the firm that provides the wire will sell you a small vial of it). This solution is the preferred way to remove the enamel covering from copper wire. After the wire has been dipped, allow it to stand for a minute, then wipe it off. The softened enamel will then peel right

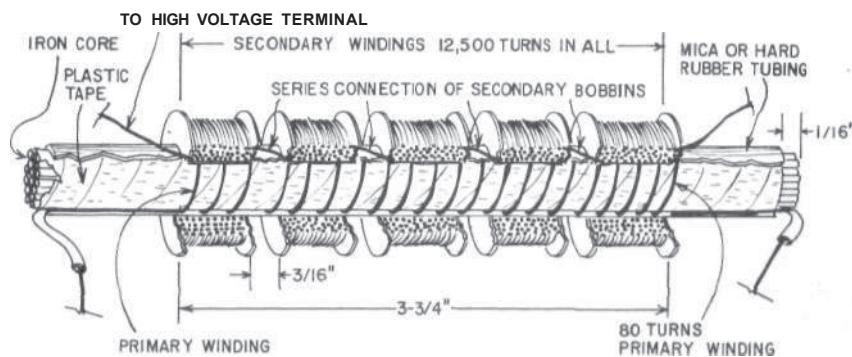


Fig. 805. The five bobbins, each containing 2,500 turns of wire, are connected in series to form the secondary.

off, leaving the bright copper exposed for perfect soldering. A note of caution: if a spot of it gets on your hands, wash them immediately with soap and water.

When all five bobbins have been finished and their wire terminals are cleaned and ready for soldering, slip one after another on the mica or hard-rubber tubing, spaced as shown in Fig. 805.

Carefully solder the end of No. 1 coil to the beginning of No. 2, and so on, until all are connected in *series* and all the turns are in the same direction around the core. Leave the beginning of No. 1

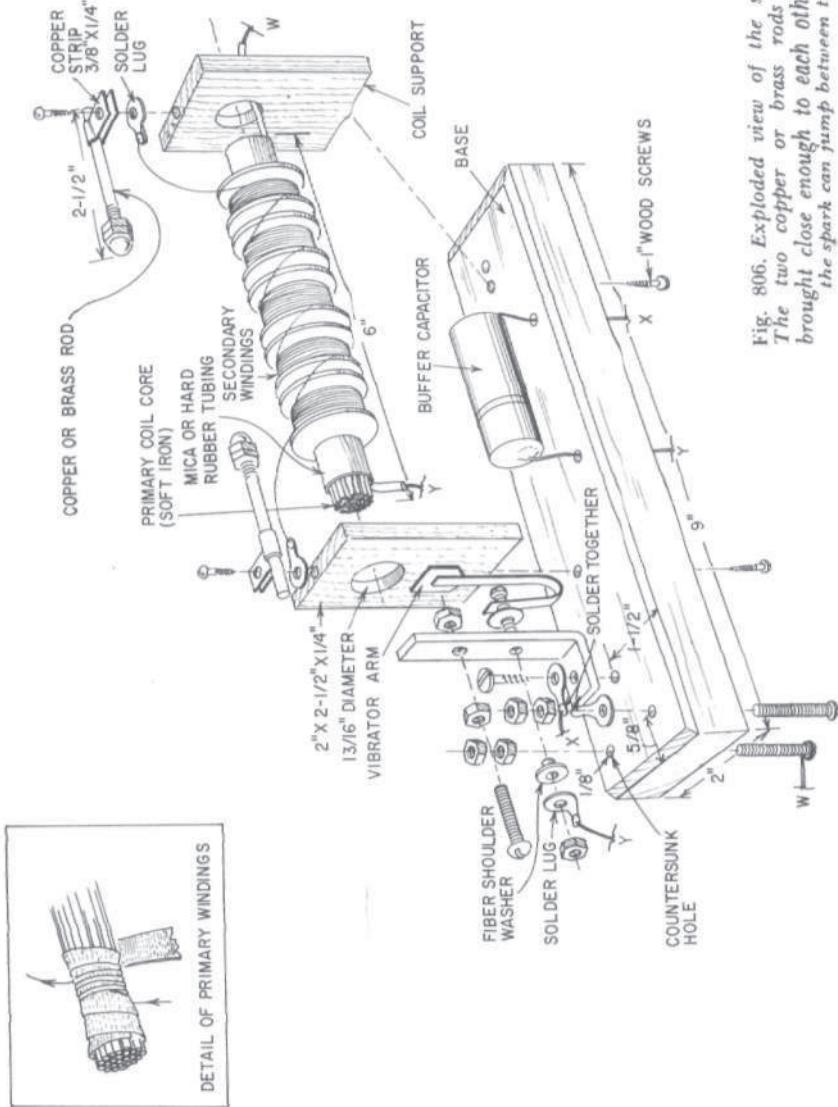


Fig. 806. Exploded view of the spark coil. The two copper or brass rods must be brought close enough to each other so that the spark can jump between them.

coil and the end of No. 5 until later, when they will be connected to binding posts.

When the soldering is complete, test for continuity. With your galvanometer and a dry cell in series, test across the two outside or high-voltage terminals of the secondary winding. If the galvanometer swings, indicating a complete circuit, bend the connections between the bobbins gently down between the coils and cement

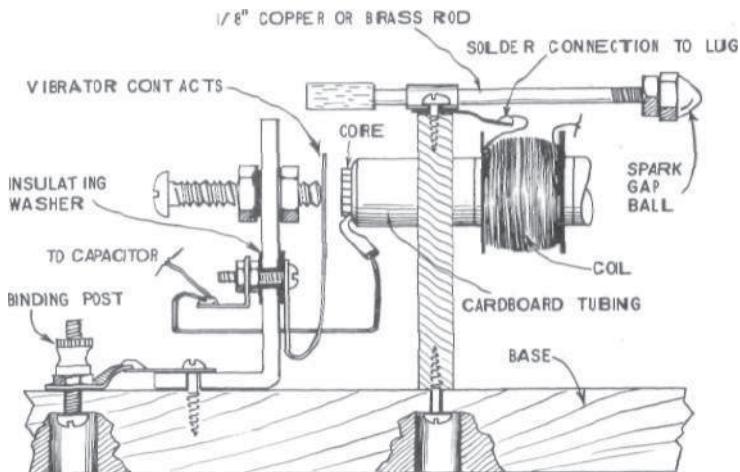


Fig. 807. Note how the end of the secondary winding is connected to the rod. It is important to insulate the vibrator arm from the L-bracket on which it is mounted.

into place. A note of caution: handle the terminal wires of each coil with the greatest care to prevent breakage. Remember that No. 38 copper wire is only about .004-inch in diameter, or slightly larger than an average human hair.

When the cement is thoroughly dry, mount the primary-secondary assembly on two $2\frac{1}{2} \times 2 \times \frac{1}{4}$ -inch pressed-wood stands through which have been bored $13/16$ -inch holes to take the mica tubing. Fix these stands to a 2×9 -inch base with metal L-brackets or wood-screws. See Fig. 806.

Mount two binding posts for the low-voltage winding (or primary.) The binding post assembly and its method of mounting is shown in Figs. 806 and 807.

Cut two strips of copper, each $3/8 \times 1\frac{1}{4}$ -inches, and bore $1/8$ -inch holes in each end. Bend around the shanks of $1/8$ -inch copper or brass rods $2\frac{1}{2}$ -inches long and fix into position with wood screws. The copper strips will allow the spark gap to be adjusted for length by pushing the $1/8$ -inch rods back and forth. Mount two

copper or brass spheres at the ends of the brass rods. The spheres will greatly enhance the brilliance and power of the spark as it flashes from one ball to the other.

parts list for the spark coil

Wire and tubing: 1 lb. No. 37 or No. 38 enameled copper wire; 40—green-coated florist's supporting iron wires; 6" length of fiber tubing 13/16" OD, 3/4" ID; 6" length of mica or hard-rubber tubing, 11/16" OD; 3 to 4 inches of flexible insulating tubing (for ends of primary winding); spool of No. 20 enameled wire. Hardware: 12—fiber washers, 1 1/4" OD 13/16" ID; 2—binding-post assemblies (for low-voltage dry-cell connections); quantity of 6-32 or 8-32 screws (brass)

and hex nuts; assortment of roundhead bright woodscrews; 6—solder-coated terminal lugs; quantity of insulating bushing washers. Miscellaneous: 1—2" x 9" base, finished with varnish; 1—vibrator-interrupter assembly from an electric doorbell (or constructed as per text); 2—spheres (1/2" diameter, for high-voltage spark gap); 1—capacitor .25 uf, rated at 200 to 400 volts dc; small quantity of sheet brass or copper; 2—2 x 2 1/2" X 1/4" pieces of pressed board.

The vibrator interrupter

The vibrator interrupter is an important part of the spark coil, since it is the device that interrupts the battery current to the primary winding. It is, perhaps, the most difficult part of the spark coil to put together. Anyone seeking to escape this job may secure the interrupter element of an old electric doorbell and use that instead. But the vibrator interrupter (shown in Fig. 808), known as a tuned vibrator, will do the job better because it operates more efficiently and at a much higher pitch.

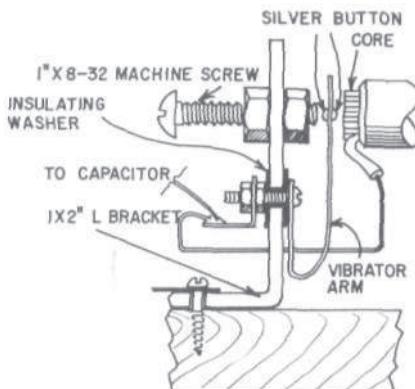


Fig. 808. Detail of the vibrator section. The 8-32 machine screw must be adjusted so that it touches the silver contact on the vibrator arm.

Building the vibrator

Secure a 1 x 2-inch brass L-bracket from any hardware store. Usually it will have two holes in the long (2-inch part) and a single hole in the other. The hole in the 1-inch leg of the bracket will be used to mount the vibrator to the base.

In the other leg, enlarge the hole nearest to the right-angle bend. to a $\frac{1}{4}$ -inch size. Fit an insulating ferrule with fiber washers into it so that a 1"x6-32 machine screw may be passed through without touching the metal part of the bracket. Place a 6-32 brass nut over the machine screw to hold the ferrule and washers loosely in place.

Stand the L-bracket assembly upright against the coil mounting and mark the height of the coil's center line on the bracket with a scribe. Bore a 3-32-inch hole at this height and thread it for an 8-32 machine screw. This calls for the use of a die, a tool which you may not have. You can avoid this by putting an 8-32 nut on the side of the screw nearest the vibrator arm.

Clamp a 1-inch x 8-32 brass machine screw in a vise between two thin pieces of wood (to prevent injury to the threads), mark the threaded end of the screw with a center punch and drill a 1/16-inch hole about 1/8-inch deep. Drive in a short piece of 1/16-inch silver wire, tapping it with a light hammer to spread the silver slightly and fix it in the hole. The silver wire should fit snugly into the hole before the hammer is used. A few gentle taps will do the job. When finished, twirl an 8-32 brass nut over the screw and lay it aside. It will be assembled later in the threaded hole of the brass L.

With tin snips or heavy shears, cut a 2 x 3/8-inch strip from the side of a coffee can. Drill a 1/16-inch hole near one end at the exact center and a 1/8-inch hole in the exact center of the opposite end. Fit a 1/8-inch piece of the same kind of silver wire through the 1/16-inch hole and fix it therein with a few taps of the hammer. Then, turn the strip of tin over and tap the other end of the wire. This should firmly rivet it into the hole and will form the second terminal of the primary spark gap.

Remove the 6-32 screw from its insulating ferrule and washers. Insert the screw through the 1/8-inch hole in the tin strip and remount the screw, ferrule and washer assembly through the $\frac{1}{4}$ -inch hole in the L-bracket. Screw the assembly firmly together with a 6-32 brass nut.

Insert the 8-32 machine screw in the threaded hole at the top of the vibrator assembly. The silver contactor should project from the L-bracket about 1/4 to 3/8-inch. Bend the tin strip so its silver

button (the second contactor) touches the first silver button (the one in the end of the 8-32 screw. (Fig. 808).

Adjust the 8-32 screw until the two silver buttons just touch (this is the ideal operating position). Then tighten the 8-32 brass nut, fixing it in this position.

Screw the whole assembly to the base so that the strip of tin will be attracted by the magnetism generated by the spark coil's iron core when current from the dry battery goes through the primary winding. The ideal position should be determined by trial.

Finally, place a terminal lug under a second 6-32 nut on the insulated 6-32 brass machine screw and tighten. Wire this lug to one end of the primary winding. Place a second lug under the woodscrew that holds the vibrator assembly to the base of spark coil and wire it to one of the binding posts. Attach the other end of the primary winding to the other binding post.

This completes the vibrator. The only thing remaining is to connect a .25-uf fixed capacitor across the spark gap to absorb the spark generated between the silver buttons when the spark coil is in operation. To do this, connect one of the capacitor's terminals to the base of the L-bracket and the other to the lug of the 6-32 brass machine screw.

The final step, of course, is to put the spark coil into operation. For this you will need two No. 6 dry cells. Wire them in series as shown in Fig. 802. The No. 6 dry cell has two terminals. One of these, the center terminal, is positive or plus. The other, mounted on or near the edge, is the negative or minus terminal.

Connect the minus terminal of one cell to the positive terminal of the other cell. Connect the two remaining terminals (one on each cell) to the binding posts on the base of the spark coil. For making these connections, use No. 18 or No. 20 pushback wire.

Move the spark coil rods close to each other, but not touching. As soon as a steady spark appears between the spark gap balls, separate the rods and try to make the spark extend over as big a distance as possible.

Experiments to try

Experiment 1

Disconnect the capacitor temporarily and measure how far the spark will jump between the secondary terminals. Then connect it and measure again. Note the ratio of distances.

Experiment 2

Secure two large brass balls and construct an additional spark gap by attaching them to brass rods mounted on two insulating

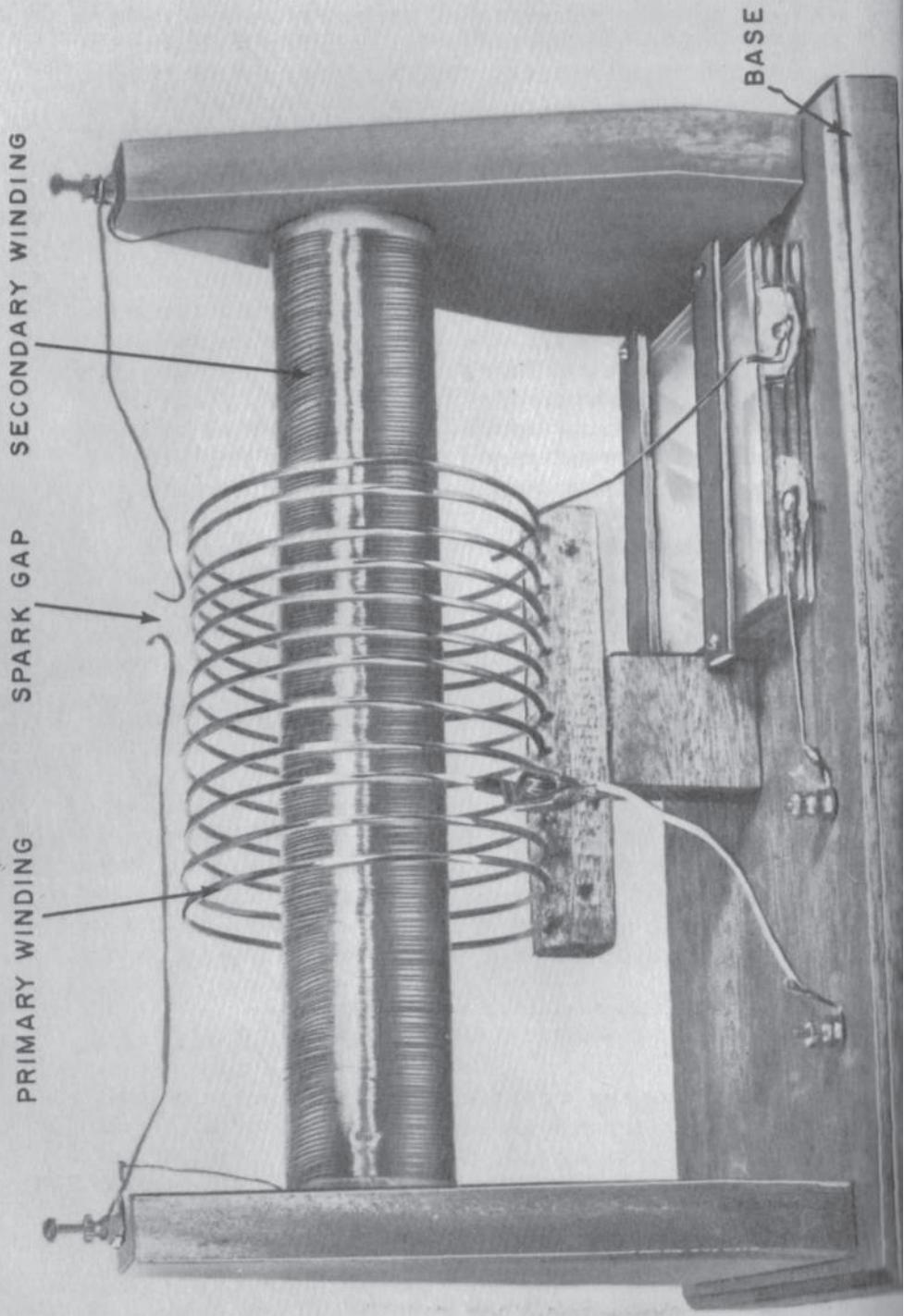
pillars. Two such balls, extending perhaps an inch or more in diameter, may be found in a store that specializes in curtain rods. Draw out the regular spark-gap balls very wide and wire the secondary terminals to the new spark-gap balls. Note that the large balls produce not only a *fatter* spark but a somewhat *longer* one. This fatter spark occurs because the large balls are acting as accumulators of the high-voltage energy in much the same way as the capacitor bridging the low-voltage spark gap.

Experiment 3

Disconnect the large balls and cement two tacks to the surfaces of the two smaller balls. Note that *no* fat spark jumps the gap between the two tacks. Why? The principle is the same as the lightning rod: a trickle or leakage of electrical energy taking place continuously in a storm prevents an accumulation of a large charge which would result in a lightning flash. Turn off the light over your workshop table and observe in the dark that this trickle discharge is a continuous process as long as the switch is pressed.

Experiment 4

Insert a piece of paper between the discharge balls and observe how readily it is pierced by the spark. Now substitute a piece of plate glass. Note that it is not pierced by the spark. Remove the glass slowly from between the balls. Notice that a point will be reached at which the spark travels around the edge of the glass. The spark test is a convenient way of finding relative insulating factors of different materials.



CHAPTER 9



the Tesla coil

NIKOLA TESLA was a man far ahead of the electrical science of his day. This wizard of the 1890's often astonished his contemporaries and left them floundering in a maze of theory and experiment that had little then to support it except his word — that one day what he envisioned would come true and be of use to mankind.

Thus he often was dismissed as a dreamer and mystic. But Tesla also was a very practical person at times, as evidenced by his invention of the induction motor and the rotary magnetic-field principle upon which it was based. Mathematics was his forte; high-frequency phenomena his delight.

Although Tesla's practical achievements in electricity were many, throughout most of his life he dreamed of something which has yet to come true — transmission of power by radio. Strangely enough, this led him to the creation of a device by which he is best known today but which is now only a laboratory curiosity — the Tesla coil.

With more than 700 patents to his credit, this Serbian genius — whose prediction was that he would live to be 140 — died at the age of 86 in a New York hotel room where he had spent the last years of his life in comparative solitude. In a final tribute to him, the Institute of Radio Engineers said: "He lived in a land of brilliant concept and dreams so lofty as to be foredoomed — a

Fig. 901. This is a photo of a completed Tesla coil. The coil is used together with the spark coil described in Chapter 8.

catalyst in the realm of technology. His passing seems, in a sense, to be the end of an epoch."

I interviewed Tesla not long before his death. Around him were scores of books, electrical gadgets and mementos of the past. "Tell all of your young readers," he said, "that it seems providential to me that the aspiring of youth or man is not blessed with a million dollars. The mind is sharper and keener in seclusion and solitude. It does not cost a million to think, and by thinking the idea is created."

Transmission of electrical power by radio was Tesla's great dream. Out on Long Island, N.Y., he spent a small fortune in the Nineties erecting a tower and installing equipment that hurled man-made thunderbolts into space. Today's Tesla coil — the laboratory curiosity from which much knowledge may still be gained — is its direct descendant.

Electrical resonance

The Tesla coil demonstrates the remarkable phenomenon of electrical *resonance*, without which radio waves could not be sent or received with anything like today's efficiency. Electrical or mechanical resonance is a property of every physical system which has one or more natural vibrations or frequencies, depending upon its length, tension and mass. Forced vibrations may be feeble, but, if the actuating force is varied until it comes into step with the natural mode of the object, the effect may be multiplied many times as exact *synchronism* is reached. This is known as its *natural period of oscillation*.

Electrical resonance is the principle of operation of the Tesla coil when its secondary or high-voltage circuit is tuned to exact synchronism with its primary winding. Since Tesla coil sparks are also of very high frequency, there is no danger of electrical shock although millions of volts may be produced that dance through the air, set electric bulbs into glowing brilliance without contact to lighting outlets and make one's hair stand on end.

The reason this happens is that Tesla coil secondary sparks are so very *high* in frequency that the electricity travels over a body's surface or skin with only a slight tingling sensation. But let us build such a device, power it with a spark coil and see what happens as the miniature thunderbolts flash about the home workshop.

How it works

The Tesla coil (Fig. 901) is a transformer induction coil whose

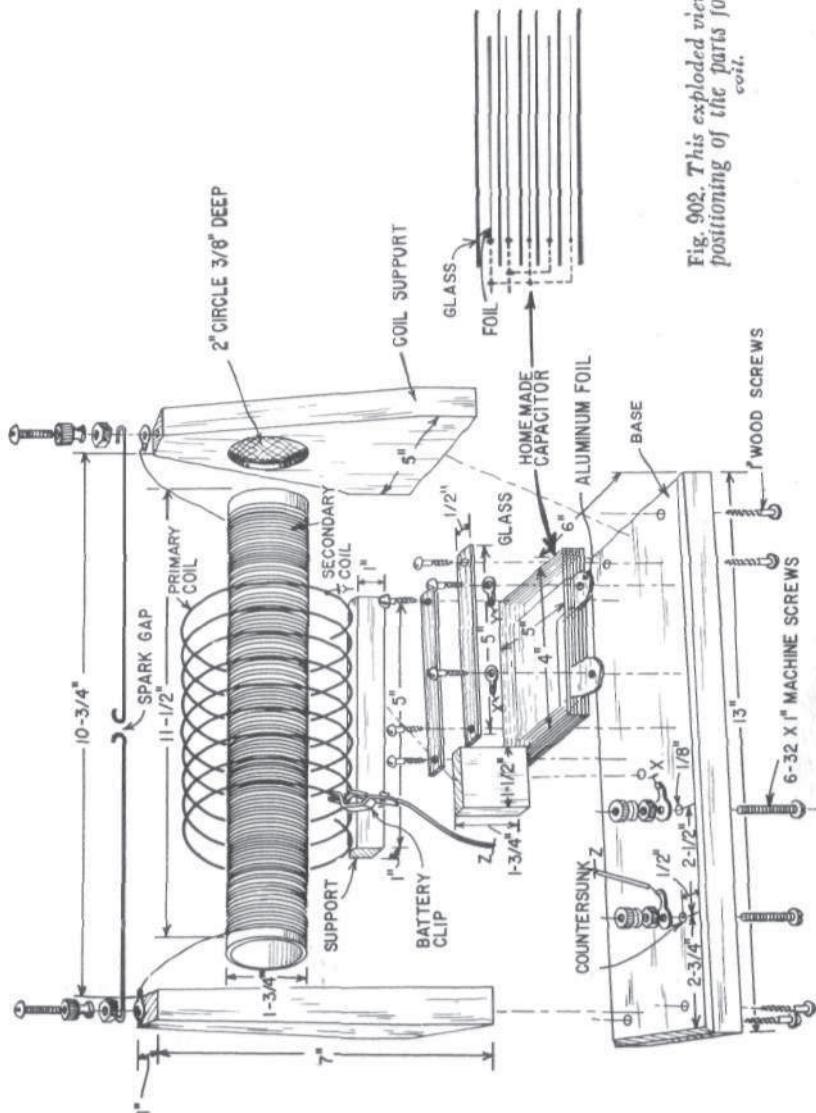


Fig. 902. This exploded view shows the positioning of the parts for the *Tetra* coil.

secondary yields an intense high-frequency discharge at voltages often in the millions. Remember how the secondary of the spark coil described earlier produced an oscillating voltage far in excess of any transformer of comparable turns ratio? Well, the Tesla coil is another such device which receives the spark coil's output and gives it another boost, utilizing the magical phenomenon of resonance. In other words, the Tesla coil's primary winding resonates with the secondary discharge of the spark coil, because they are *tuned* to be in step with each other electrically.

This may be done either by adjusting the spark gap of the spark coil or by adjusting the number of turns in the Tesla coil's primary winding by moving the clip from turn to turn. When the right combination of turns produces an oscillation in the Tesla primary that is an exact multiple of the oscillations to which the Tesla secondary can easily respond, another set of oscillations produces a torrent of high-frequency sparks across the Tesla coil's secondary terminals.

Thus, the two related sets of resonant oscillations may transform (or magnify) the voltage of a few dry cells into the millions. It can only be compared with the tremendous electrical discharges of a lightning flash.

Building procedure

Secure a cardboard mailing tube $1\frac{3}{4}$ inches in outside diameter and $11\frac{1}{2}$ inches long. Wind a $10\frac{1}{2}$ -inch portion of it (properly centered) with No. 36 or No. 38 silk- or cotton-covered copper wire, spaced one diameter apart (the way to do this is to wind the copper wire and a black thread of equal diameter side by side). Hold the wire taut and coat immediately with hot melted paraffin, then unwind the thread after the paraffin has cooled. This will make each turn of the winding equally spaced from the next by the amount of the width of the thread. Then, apply another coat of melted paraffin with a small paint brush.

Build a wooden frame with a base 6×13 inches (Fig. 902). The truncated pyramid ends should have 5-inch bottoms and be 7 inches high. The ends should be bored partially through to produce a 2 inch circle, $\frac{3}{8}$ inch deep, starting about two-thirds from the bottom.

Fit the ends of the cardboard tube and winding therein and cement one end in place. Attach the wooden ends to the base with 1-inch woodscrews and countersink them under the base.

Attach a high-voltage binding post to the top of each of the wooden ends and connect each end of the high-voltage winding

to each post. The binding posts may be constructed of roundhead 8-32 machine screws and hex nuts. The screws should be brass and

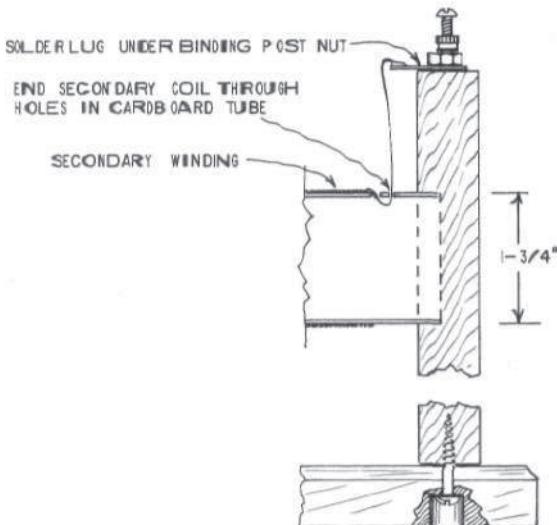


Fig. 903. The coil form for the secondary winding is supported by the truncated pyramid side piece. Note how the secondary winding is connected to the terminal under the binding post.

fitted with knurled-head nuts in the usual binding post manner. This is shown in Fig. 903.

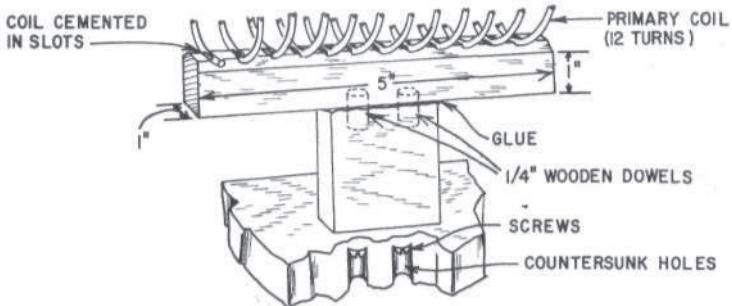


Fig. 904. The primary coil is mounted on a wooden support. Do not cement the wooden dowels into place until the Tesla coil operates the way it should.

Normally, we use wood screws, not machine screws, when fastening to wood. However, wood can be made to hold machine screws also. Mark the spot on the top of the wooden side piece where you plan to insert the screw. Drill a straight, vertical hole having a

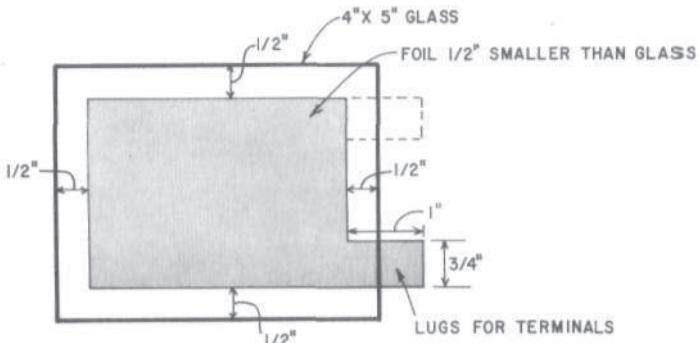


Fig. 905. This shows the general shape of the foil and the glass. The $\frac{1}{4}$ -inch tab of aluminum extending beyond the glass requires a center hole for a 6-32 machine screw.

diameter smaller than that of the screw. The hole should have a depth slightly longer than that of the screw.

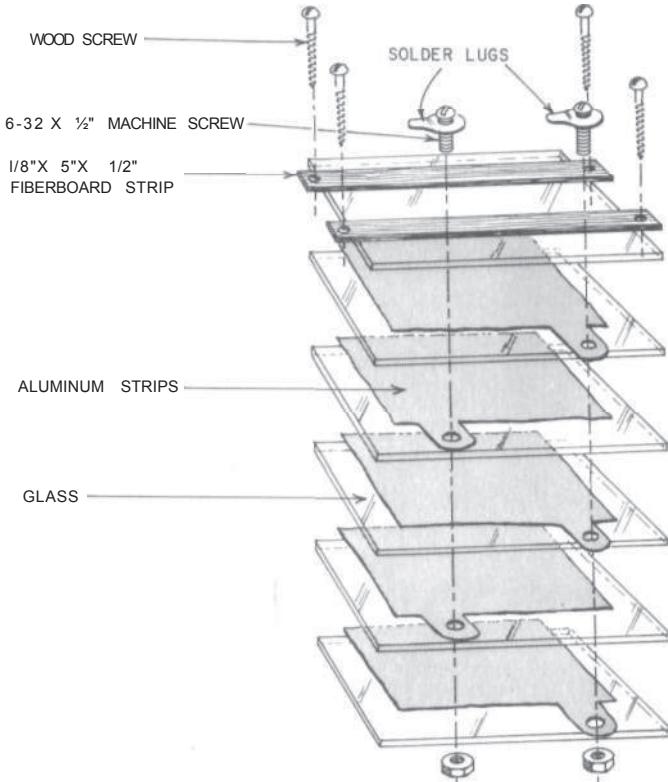


Fig. 906. This is an exploded view of the capacitor assembly. Alternate strips of aluminum are electrically connected by machine screws.

Using a screwdriver, turn the machine screw into the wood. As you do, threads will form inside the drilled hole. Turn the screw

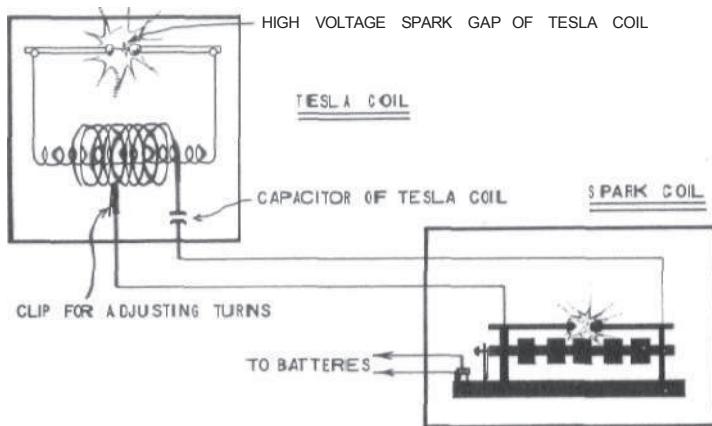


Fig. 907. This is the complete circuit of the Testa coil. Note how it is connected to the spark coil.

for its full length, then remove carefully. Be sure to keep the screw vertical when doing this. You will now have a tapped hole which will support the binding post assembly.

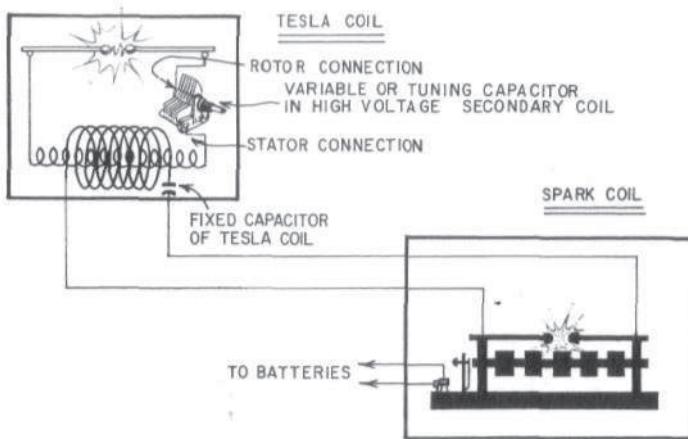


Fig. 908. The addition of a variable capacitor makes the Tesla coil into a tuned circuit.

Procure 12 or more feet of No. 8 or No. 10 bare copper wire (if only insulated wire is available, shave off the insulation with a sharp knife) and wind it on a large-size tin can (such cans are exactly 4 inches in diameter).

Mount the primary coil (12 turns) thus formed on a dry wood support. The top member of the supporting frame should "be 5 inches long and notched every $\frac{1}{2}$ inch with a hacksaw. Spread the coils by pulling gently on each end until it is of the right length, then push each turn into one of the slots and cement in place. See Fig. 904.

Remove one of the truncated pyramid verticals by removing the screws under the base and sliding it off the secondary coil, which was left uncemented for this reason.

Mount the primary over the secondary so that the clearance between the two is equal all around. If the primary coil is too high, shave off a small portion of the bottom supporting block.

Pin the two blocks together with small lengths of $\frac{1}{8}$ -inch wooden dowel. The dowels should not be cemented as it may be necessary to remove the primary later on for alterations. Screw the bottom block to the base, press the $\frac{3}{4} \times \frac{3}{4}$ -inch dowels into the holes bored in the bottom block, as shown in Fig. 904.

Make the capacitor in the primary circuit by cutting six 4- by 5-inch pieces of window glass and five pieces of kitchen aluminum foil with aluminum lugs as shown in Fig. 905. Alternate the glass and aluminum sheets and screw to the base with two strips of 1/8-inch pressed wood or fiberboard. The strips should be about 5 inches long and $\frac{1}{2}$ inch wide. See Fig. 906.

Complete the actual construction of the Tesla coil by installing two binding-post assemblies. Connect the capacitor into the circuit (Fig. 907) and attach the Tesla coil to the spark coil (they operate as one unit).

After you have connected the Tesla coil and the spark coil, adjust the rods of the Tesla coil. Compare the size of the spark with that of the spark coil. Move the spark coil rods back and forth slightly. Note how this can be used to control the size of the spark of the Tesla coil.

parts list for Tesla coil

Wire: 1 lb. No. 36 or 38 cotton- or silk-covered copper wire (for secondary winding); 12' of No. 8 or 10 bare copper wire (if insulated, scrape off insulation with a sharp knife); V of heavy flexible copper wire.

Hardware: 6—8/32 x 1" brass machine screws; 1—alligator clip; 4—binding-post assemblies.

Miscellaneous: 1—6 x 13" base, varnish-finished; 2—5 x 7" pyramid ends (sawed in the form of truncated cones); 1—piece

cardboard tubing, $1\frac{1}{2}$ " long x $1\frac{3}{4}$ " in diameter; 1—piece of the same wood as the base, 5" long x 1" thick x 1" wide; 1—2 x 2" block of the same wood (for central support of the primary coil); 2—1" pieces of $\frac{1}{4}$ " wooden dowel; 6—4 x 5" pieces of window glass; 5—pieces of kitchen aluminum foil (cut with lug terminals as in Fig. 905); 2—5" long x $V2$ " wide x 1/8" thick pieces of pressed board; 2—1" copper or brass spheres (with wire connectors, for high-frequency terminals).

Experiments to try

Experiment 1

The Tesla coil is a step up transformer having a primary winding (12 turns) and a secondary winding of many more turns. Because we connected a capacitor to the primary we "tuned" it, somewhat in the manner in which you "tune" a broadcast receiver to select certain stations.

We can also tune the secondary of the Tesla coil by inserting a capacitor as shown in Fig. 908. But this time let us use a variable capacitor—one whose plates can be turned. This capacitor, which you can buy in a radio parts store, should have a value of .0001 microfarads. Put a knob on it so you can turn it easily.

The variable capacitor has two sets of plates. The fixed plates are called the stator. The plates which can be rotated are called the rotor. Each set of plates should have a small lug to which you can solder a wire.

Disconnect one of the wires going from the secondary winding to the rod of the Tesla coil. Solder a pair of wires to the rotor and stator lugs of the variable capacitor. One of these wires should now be connected to the rod, the other to the secondary coil.

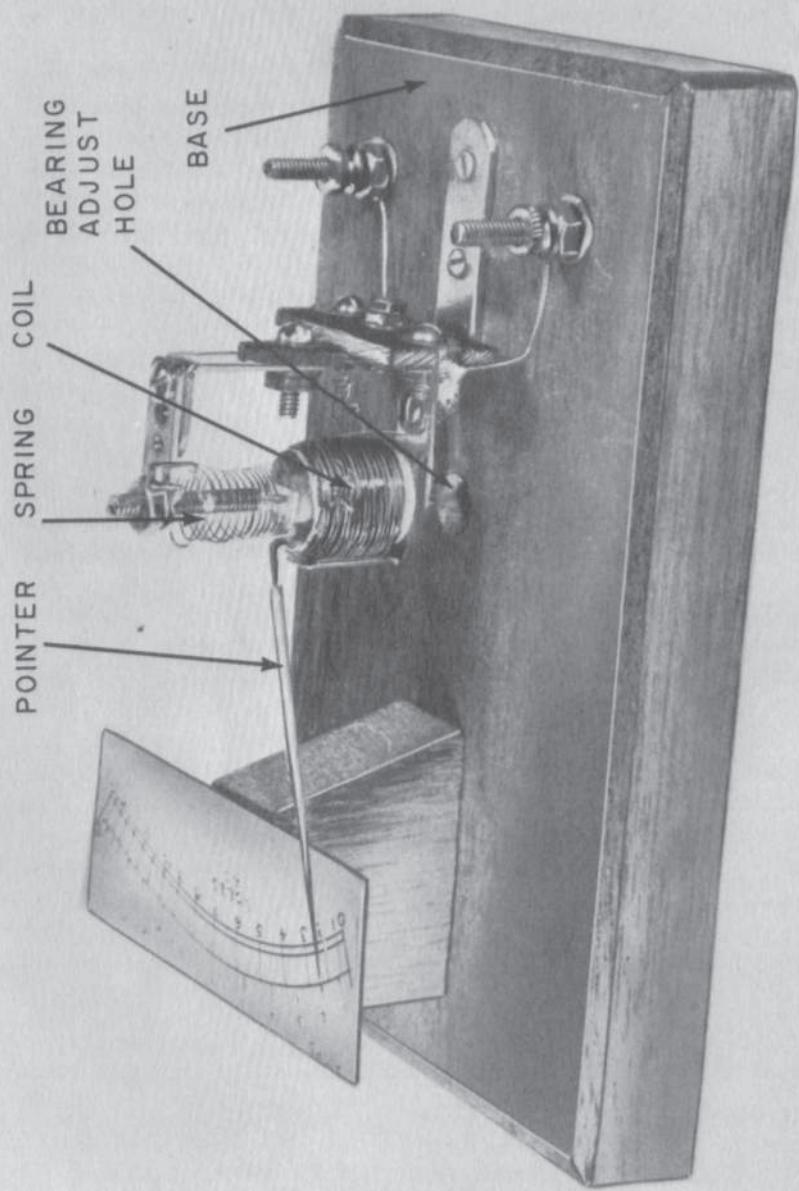
Adjust the rods until you get a spark. Turn the shaft of the variable capacitor. Note how you can control the spark. This is a much finer method of control than adjusting the rods. You will probably be able to get a much bigger spark.

Experiment 2

Holding a 117-volt electric lamp, bring it near one of the high-voltage balls and see how the lamp glows (Fig. 909).



Fig. 909. *Electronic magic! Light the bulb without using connecting wires.*



electrical meters



No DEVICE in electricity is more important today than the measuring instrument or meter. Commercial electrical meters gauge and record the flow of power from generating stations to our homes. Laboratory work would be slowed immeasurably without them. Factories, broadcast stations, airplanes and railroads could not operate at top efficiency without a wide variety of meters to indicate what is going on in all sorts of electrical circuits.

Moving-iron meter

Perhaps the simplest electrical meter is the *moving-iron type*, in which two small pieces of soft iron are mounted side by side within the turns of a magnetizing coil of wire. One piece of iron is fitted with a spindle and pointer, and is free to rotate on delicate bearings through part of a circle. The other piece of iron is mounted so it cannot move. When either ac or dc is sent through the winding, magnetic repulsion occurs and the pointer moves over a scale calibrated in volts or amperes. A coiled spring returns the pointer to zero when the current is turned off.

Dynamometer (or electrodynamometer)

Another type of basic measuring instrument is the *dynamometer*, in which a rotating coil carrying an indicating pointer moves within a somewhat larger fixed coil. With the two coils connected in series and the current turned on, the moving element attempts

Fig. 1001. The completed moving-iron meter. The commercial version is known as an iron-vane meter.

to orient itself within the other so there will be the least interference between the two sets of lines of force.

d'Arsonval type (the galvanometer)

The third type of electrical instrument, perhaps the most sensitive and widely used of all, is the important d'Arsonval movement, in which a very light coil of fine wire is arranged to move within the field of force or poles of a permanent U-shaped magnet.

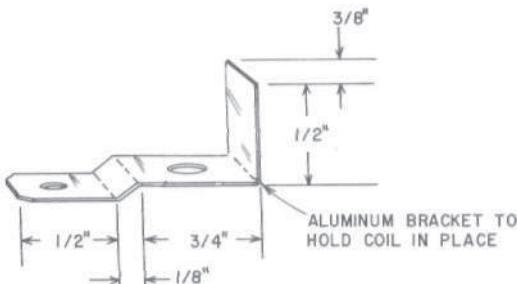


Fig. 1002. An aluminum bracket for the meter coil can be snipped out with a pair of scissors and bent to suit.

The variety and application of electrical meters are almost without number, so great has been their increase since Prof. Hans Christian Oersted in 1820 discovered the basic principle of the galvanometer while lecturing to his class in Copenhagen.

Oersted had noticed that an electric current, when passed through a wire he was holding near a magnetic compass needle, caused the needle to swing as if influenced by another magnet. Investigating more thoroughly later on, he established the foundation for all future development of practical measuring instruments.

The most widely applied meter movement, however, did not appear until 1882, when Arsene d'Arsonval, a French physicist, designed and invented the instrument, much as it is today.

The three electrical meter types utilizing a modified type of moving-iron meter, the electrodynamicmeter and the d'Arsonval movements were built by the author in one week. No attempt was made to get the most efficient results; that is, the greatest deflection for the amount of current passing through the meter. On the other hand, simplicity of construction was deemed of the utmost importance so that the principles involved might be readily studied by direct observation of the mechanical-electrical arrangement of parts. No instrument was housed in a case which

would serve only to shut off one's view of the manner in which such instruments are constructed.

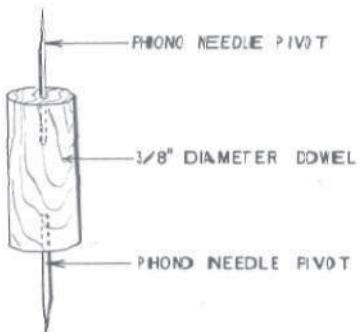


Fig. 1003. Two long-shank steel phonograph needles are inserted and cemented in each end of the dowel with their points facing outward.

In the d'Arsonval meter movement, the pivoted coil was designed to conform to the type of U-shaped, magnet most easily secured, rather than trying to find a magnet that would fit the most accepted type of coil to secure the greatest deflection of the needle. (See Fig. 1001.)

Building procedure (moving-iron meter)

Place two soft-iron wires in the opening of a solenoid and turn on either an alternating or direct current. The wires immediately

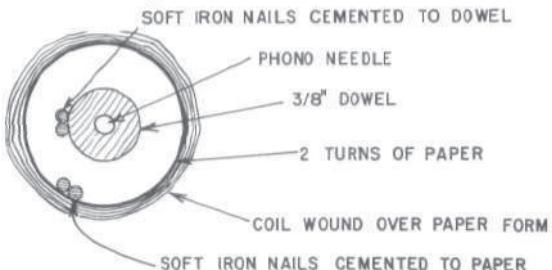


Fig. 1004. Cement two pieces of soft-iron nails inside the coil and two to one side of the 3/8-inch dowel.

spring violently apart by magnetic repulsion. Fix one wire firmly in place and mount the other off center on a pair of conical bearings, attach a pointer, and we have the elements of the moving-iron armature measuring instrument.

Prepare a 7- x 4-inch base and fit with two binding posts.

Wind 600 turns of No. 34 or 35 enameled copper wire on a 5/8-inch wooden dowel, using the dowel as a temporary coil form. Employ the winding technique described earlier in the chapter on the solenoid. Cement the turns firmly in place.

Construct an aluminum bracket (Fig. 1002) on which to mount the coil, first placing a bit of black plastic tape directly over the

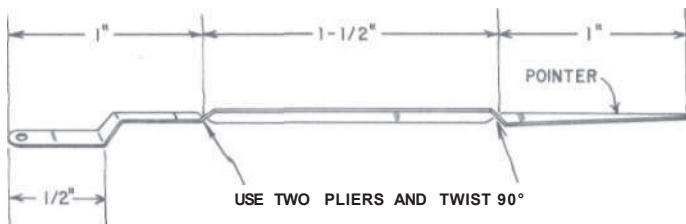


Fig. 1005. A 3½-inch sliver of thin aluminum for the meter pointer-is bent and shaped with two pairs of pliers.

wire to prevent grounding or shorting. The bracket can be snipped out easily with scissors and bent to suit.

Secure a 52-foot skein of .006-inch diameter model airplane steel bracing or guy wire (Pylon brand class $\frac{1}{2}$ A) obtainable at local sports and hobby shops, and wind 20 turns of it on the

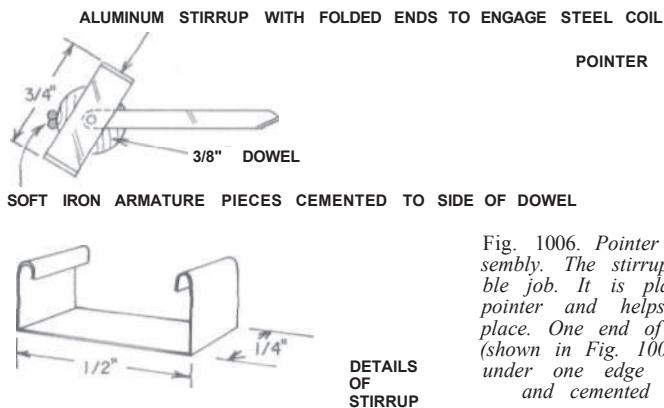


Fig. 1006. Pointer and dowel assembly. The stirrup has a double job. It is placed over the pointer and helps keep it in place. One end of a steel spring (shown in Fig. 1007) is fastened under one edge of the stirrup and cemented into place.

shank of a 1/8-inch steel drill. Place the drill in the chuck of the hand-operated boring tool (commonly called an eggbeater), with the sharp bit or drilling end in the chuck. Loosen the chuck slightly and wedge the end of a 3-foot piece of the steel wire in it alongside the drill and clamp tight.

Using a pair of pliers held in the right hand, hold the other end of the steel wire and pull it taut, while the left hand turns the handle of the drill holder, winding the steel wire around the shank of the drill.

With the left hand clasped tightly over the steel wire coils on the drill, release the right-hand hold on the end of the wire. Open

the fingers of the left hand, allowing the wire to unwind as slowly as possible. This is very *important*, as the coil will snarl if released

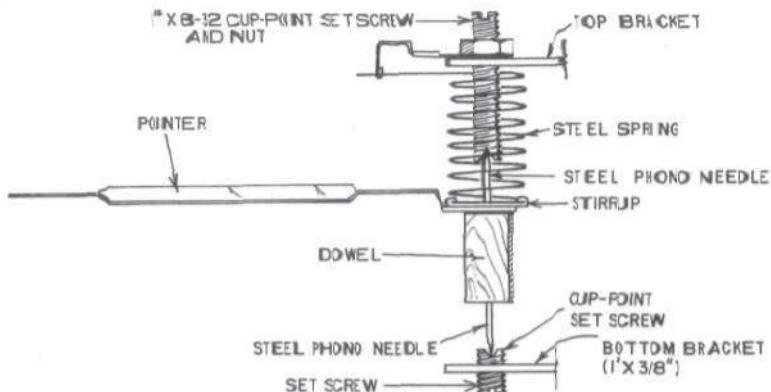


Fig. 1007. The steel spring is compressed between the top bracket and the stirrup (fastened to the dowel).

too quickly. Depending upon how taut the steel wire is held in the winding process, the coil will spring outward to a diameter of between $3\frac{1}{8}$ - and $\frac{1}{2}$ -inch. You may have to wind several coils before a suitable one is produced.

Snip off about 14 turns — the ends of the coil will usually be

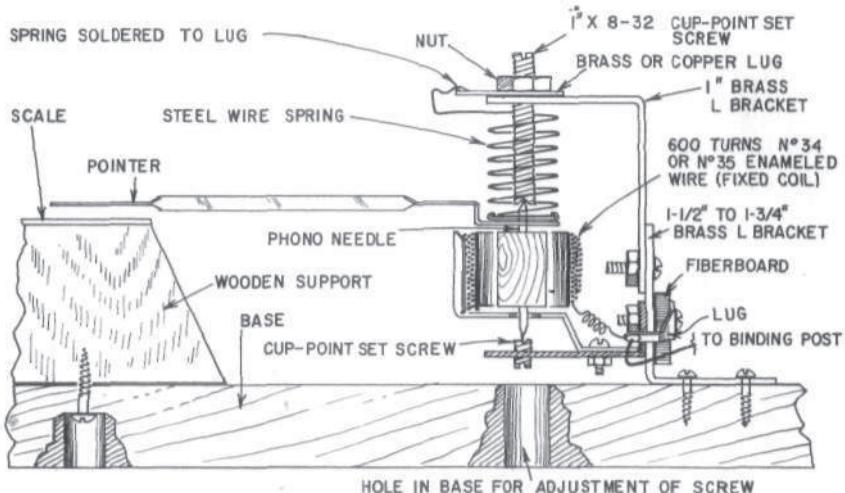


Fig. 1008. Details of the pointer assembly. The bottom end of the spring is crimped under one end of the stirrup. Adjust the position of the pointer so that it is free to move above the scale without touching it. Adjust the cup-point set screw at the bottom so that the dowel (to which the pointer is fastened) can turn freely and yet not wobble.

ragged and of uneven diameter — and stretch the turns to an overall length of about 1-inch.

Straighten each end of the coiled wire to about a 1½-inch length.

Anneal an 8-penny finishing nail in a gas flame and allow it to cool slowly. Cut off four ½-inch lengths and file the ends of each piece smooth.

Cut a piece of 3/8-inch wooden dowel about ½-inch long and drill a hole in the center of each end. Insert and cement in each end two long-shank steel phonograph playing needles (old-style) with the sharp end of each needle pointing outward from the dowel (Fig. 1003). The hole in each end of the dowel should be slightly smaller than the diameter of the shank of the phonograph needle.

Cement two pieces of the soft iron nails inside the coil and the other two to one side of the 3/8-inch dowel (Fig. 1004).

Cut a 314-inch sliver of thin aluminum for a pointer and straighten and bend as shown in Fig. 1005. Cut an aluminum stirrup and bore a hole as in Fig. 1006. Cement the pointer to the top of the dowel and then cement the stirrup over the phonograph needle. Finally, cement the first one or two turns of the steel coil to the ends of the stirrup (Fig. 1007).

Construct a 1½-inch brass L-bracket fixture. Drill holes for 8-32 brass machine screws.

Prepare a 3/4-inch x 1 ½-inch pressed board (fiberboard) for the terminals of the coil winding and fit with brass lugs. Attach this to the 1 ½-inch L bracket.

Secure a piece of aluminum, 1 3/8 inches long by 3/8 inch wide. Make a small L bracket out of it by bending a right angle at one end. Bend at a distance of 3/8 inch from the end. This will be the bottom bracket and will be used to hold the Parker-Kalon set screw. Drill and tap a hole for an 8-32 screw.

Insert an 8-32 x 3/16-inch cup-point set screw in the bottom tapped hole. Saw the head off a 1-inch x 8/32 brass machine screw. Cut a screwdriver slot in one end, bore a 1/16-inch hole in the other and to a depth of 1/16-inch, and mount in the top of tapped hole (Fig. 1008).

Cut out a copper lug. Install the lug over the upper end of the 1-inch cup-point set screw and place an 8-32 hex nut on it to hold the lug in place.

Assemble as shown in Fig. 1009, soldering the coiled steel spring

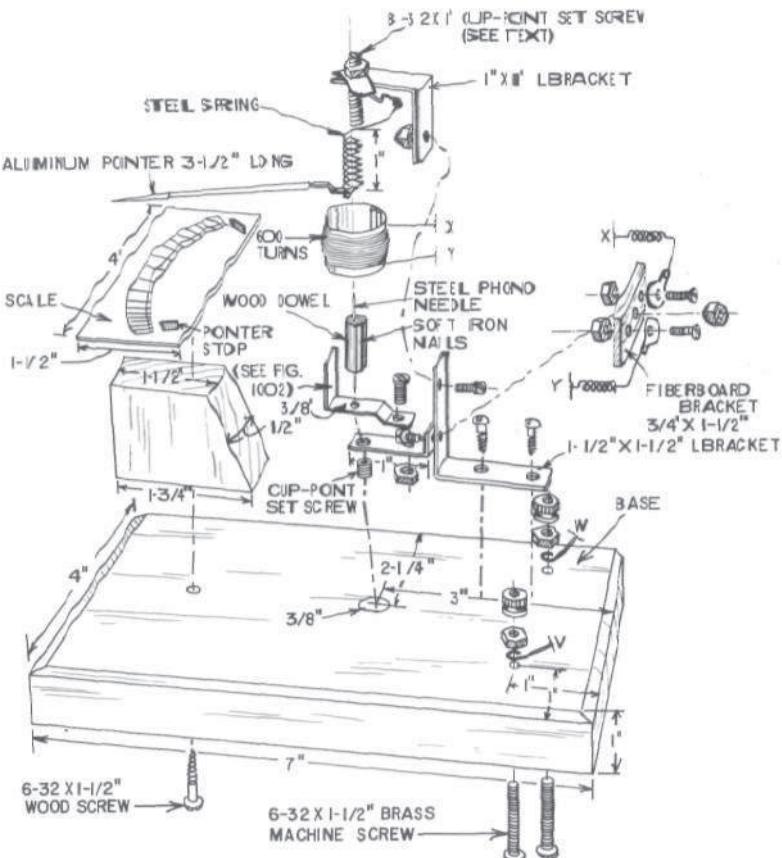


Fig. 1009. Exploded view of the moving-iron meter.

parts list for the moving-iron meter

Wire: spool of No. 34 or No. 35 enameled; 52-foot length of 0.006-inch diameter model airplane steel bracing or guy wire (Pylon brand class $\frac{1}{2}$ A).

Hardware: 2—6-32 x 1 $\frac{1}{2}$ inch brass machine screws; 3—6-32 x $\frac{1}{2}$ inch machine screws; 1—8-32 x 1 inch machine screw; 2—8-32 x $\frac{1}{2}$ inch machine screws; 3—6-32 x $\frac{1}{2}$ inch wood screws; 3—6-32 hex nuts; 3—8-32 hex nuts; 1—cup-point set screw (8-32 x 3/16 inch); 2—6-32 knurled nuts; 3—8-32 hex nuts; 1—cup-point set screw (8-32 x 3/16 inch); 2—6-32 knurled nuts; 3—soldering lugs; 1—soft-iron nail (8-penny finishing nail cut into 4

sections); 1—1 x 1 inch brass L-bracket; 1—1 $\frac{1}{2}$ x 1 $\frac{1}{2}$ inch brass L-bracket; 2—steel phono needles.

Miscellaneous: Wood base, 7 x 4 x 1 inch; wooden pedestal, 1 $\frac{1}{4}$ inch bottom, 1 $\frac{1}{2}$ inch top x 1/2 inch; cardboard scale, 1 $\frac{1}{2}$ x 4 inches; 5/8 inch wood dowel (as temporary coil form); wood dowel, 3/8 inch diameter x 1/2 inch long; aluminum strip for pointer, 3Vi inches long; aluminum strip for meter coil bracket, 1 7/8 x 3/8 inches; aluminum strip for stirrup, 3/16 x 3/4 inch; aluminum strip for bottom bracket, 1 3/8 x 3/8 inches; pressed board (or fiberboard) bracket, 4 x 1 $\frac{1}{2}$ inches.

to the brass lug. The steel wire will solder to the copper lug if the wire is *tinned* thoroughly with a hot iron.

Solder the ends of the enameled copper wire to the brass lugs and then connect the lugs to the binding posts. This completes the electrical circuit.

Mount a wooden pedestal centrally on the base and cement a $1\frac{1}{2}$ - x 4-inch piece of cardboard on it, as a foundation for a calibrated scale. Draw a scale a little less than 4 inches wide and attach with cement.

Adjust the pointer to zero setting on the scale by moving the copper. Adjust the 8-32 nut tight to hold the pointer in this position. Attach cardboard stops at each end of the calibration to prevent the needle from swinging too far.

Cement a piece of thin paper on the pointer as a damper, and the assembly job is finished. The paper should be trimmed so it will swing freely past the wooden pedestal supporting the scale.

Electrodynamometer

Andre Marie Ampere, French physicist and mathematician of the nineteenth century, was a self-made electrical scientist. Perhaps his greatest contribution was a notable series of experiments that proved all magnetic effects could come from electric currents in wires.

Ampere's greatest discovery about electric currents is the basis of the electrodynamometer meter unit of this chapter. An out-growth of his work came into being as a device called *Ampere's frame* which was the first of a family of many instruments now widely employed to measure not only the amperes in a circuit, but voltages as well, and the product of both—watts. An exploded view of the unit we are going to build is shown in Fig. 1010 and a photo and drawing showing the assembly appears in Figs. 1011 and 1012.

Building procedure

Prepare a 4- x 7-inch base, varnish in the usual manner and fit with two binding posts.

Wind two coils of No. 34 or 35 enameled copper wire. Wind about 480 turns of the first coil on a bobbin (winding form) $7/8$ -inch in diameter, $5/16$ -inch long. Then wind 240 turns of the second coil on a bobbin $7/16$ -inch in diameter, $\frac{1}{4}$ -inch long. Cement the coil turns thoroughly to secure them in shape and allow to dry. When the cement is completely dry, remove the coils from the winding forms. Leave 6-inch leads on each coil and clean the ends for soldering.

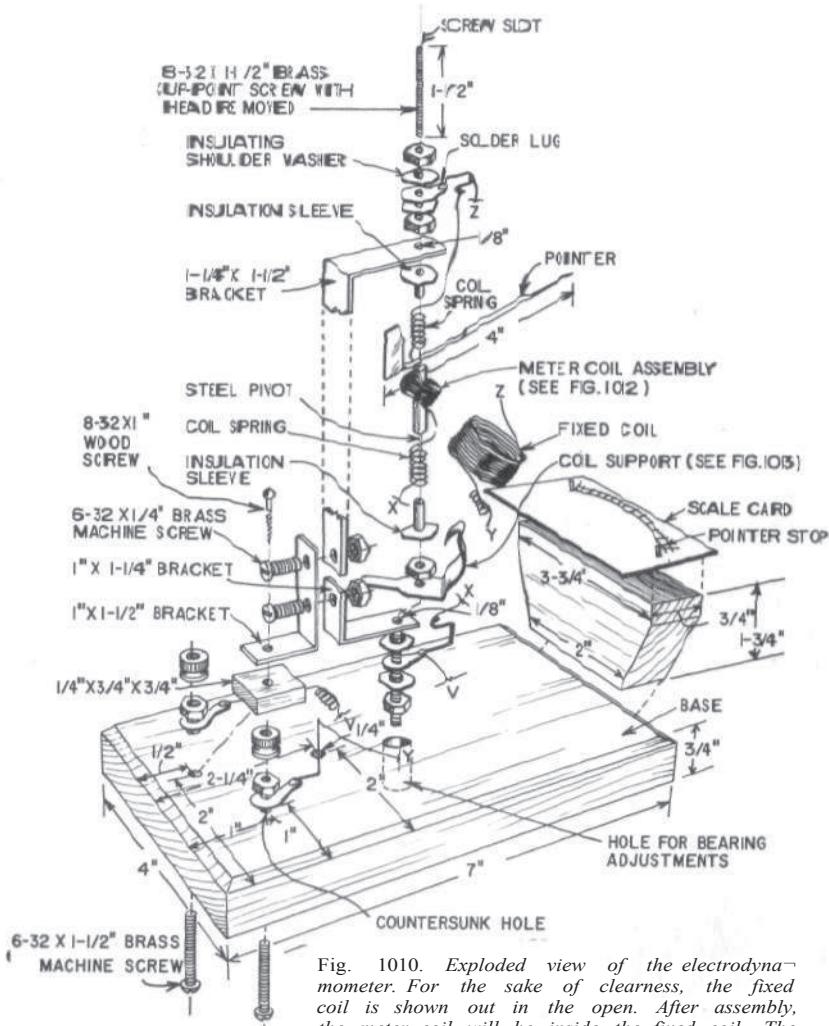


Fig. 1010. Exploded view of the electrodynamometer. For the sake of clearness, the fixed coil is shown out in the open. After assembly, the meter coil will be inside the fixed coil. The fixed coil is mounted on the coil support.

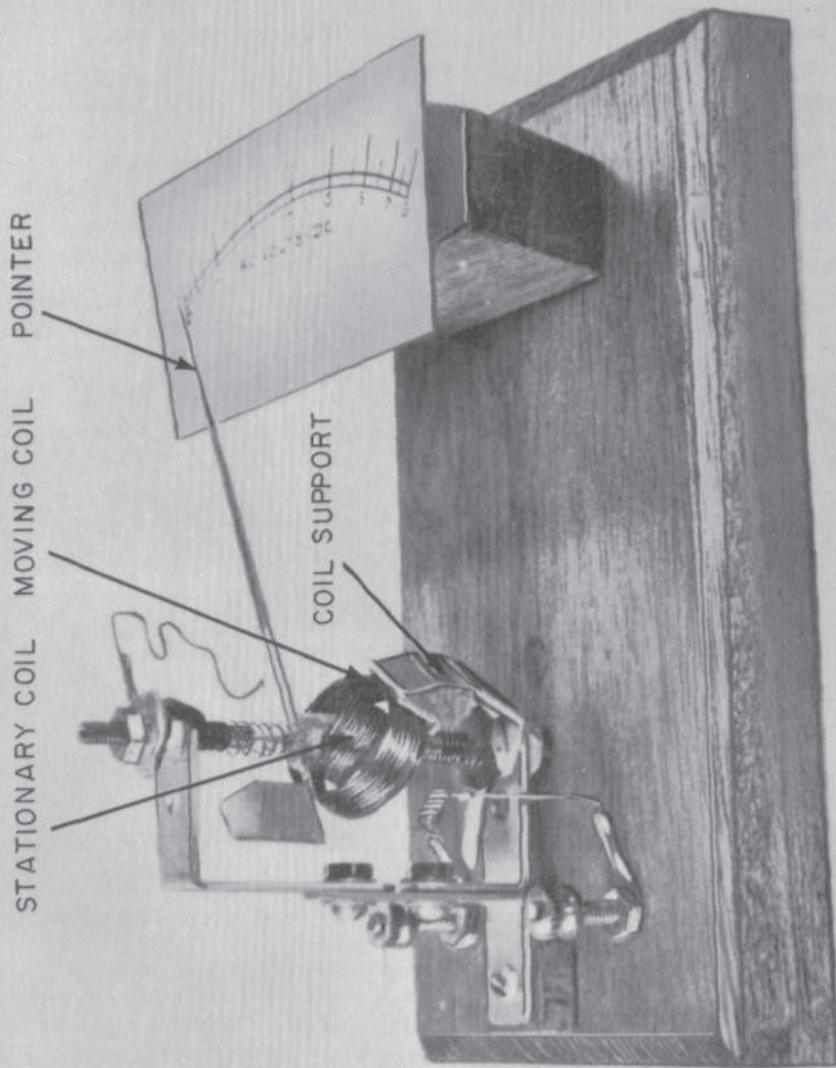
parts list for the electrodynamometer

Wire: spool of No. 34 or No. 35 enameled wire.

Hardware: 2—6-32 x 1½ inch brass machine screws; 2—6-32 x ¼ inch brass machine screws; 2—8-32 x V/2 inch brass machine screws (remove heads—cut slots for screwdriver adjustments); 6—8-32 hex nuts; 2—6-32 hex nuts; 2—8-32 knurled nuts; 4—soldering lugs; 2—8-32 x 1 inch wood screws; 1—L bracket, 1½ x 1½ inches; 1—L-bracket, 1¼ x 1 inch; 1—L-

bracket, 1½ x 1 inch; 2—steel phonograph needles.

Miscellaneous: wood base, 4 x 7 x ¾ inches; bobbin, 7/8 inch diameter; dowel, ½ inch diameter, ½ inch long; cardboard scale, 2 x 4 inches; pressed board or wood, Vi x ¼ x ¾ inches; 2—insulation sleeves; 1—4 x Vi inch aluminum strip for pointer; 1—¾ x ¾ inch aluminum strip for damping vane; 1—3 x ½ inch aluminum strip for bracket; 1—1 ¾ x ¾ inch aluminum strip for scale support.



Cut a 5/8 inch length of a 3/8-inch diameter dowel, bore each end to size and insert long steel phonograph needles for bearings,

Whittle away a section of the dowel and cement the second coil in place. The coil's axis should be about 45° from a line between the bearing points of the phonograph needles. (Fig. 1011).

On a short piece of 1/4-inch dowel rod, wind 18 turns of No. \$4 or 35 enameled copper wire to form a needle-restoring coil spring and clean the ends for soldering. Then prepare a second spring wound in the opposite direction (enameled copper wire is used

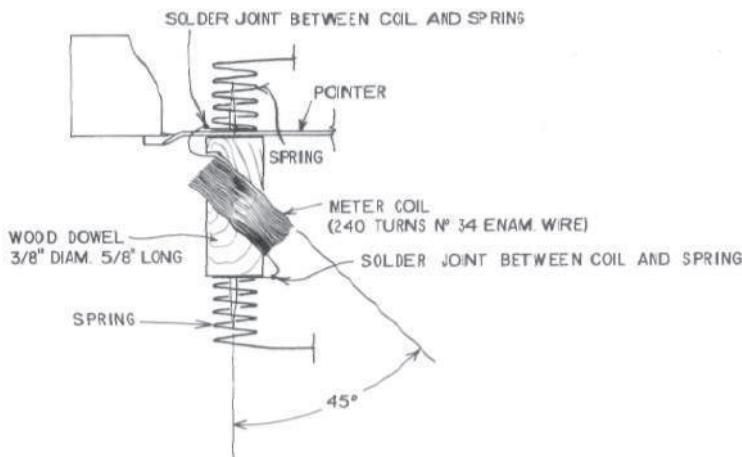


Fig. 1011. Assembly of the meter coil. Notch the wooden dowel so that the coil rests securely on it. A few dabs of Duco will hold the coil in place.

for the coil springs because steel wire is too stiff to permit a freely moving indicating needle over the whole scale). Solder the end of one coil spring to the terminal of the small mounted bobbin and the other coil-spring end to the other terminal of the bobbin.

Prepare a 4-inch instrument needle or pointer and cement it to the 3/8-inch diameter dowel close to the top steel phonograph needle. This finishes the rotating element of the dynamometer.

Assemble three brass L-brackets thus forming a mounting fixture for the final assembly of both large and small windings, terminals, etc. The mounting fixture should have a width of about 2 1/4 inches between top and bottom brackets.

Fig. 1012. The electrodynamometer uses two coils. These coils become electromagnets when a current flows through them. When the current stops flowing the coils lose their magnetism.

Both coils must be completely insulated from the L-bracket assembly. Insulation should be extended over the 8-32 x 1-inch brass machine screws to prevent the coil springs from touching the L-brackets and the machine screws.

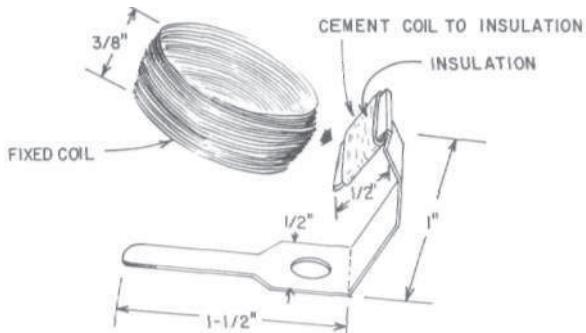


Fig. 1013. *The fixed coil is supported on a bracket shaped as shown.*

Prepare an aluminum bracket to support the larger coil. This coil is normally stationary, but it may be moved radially to achieve the correct electrical or magnetic balance between the coils during the process of calibration. The aluminum bracket may be bent slightly for complete mechanical clearance between the coils (Fig. 1013).

Mount brass lugs between the insulating washers to prevent them from touching the L-bracket frames. The aluminum bracket that holds the larger coil in place, however, need not be insulated from the frame. Note that every part of the electrical circuit is well insulated from the L-frames. The larger coil is also insulated (where it is cemented to the aluminum bracket) by a short piece of black plastic tape wound around the aluminum, before the coil is cemented to it.

This brings us to the business of connecting the coils together to effect clockwise rotation (as the instrument is viewed from the top). Connect one lead from the large coil to the nearest binding post. Solder the other lead to the top lug between the insulating washers. Also, solder to this lug the coil-spring lead from the smaller (or rotating) coil, thus electrically joining the two coils in a series connection. Solder the bottom coil-spring lead to the bottom lug between the two insulating washers, and join the lug by soldering it to the other binding post. See Figs. 1014 and 1015.

If the rotating coil turns in a counterclockwise direction when

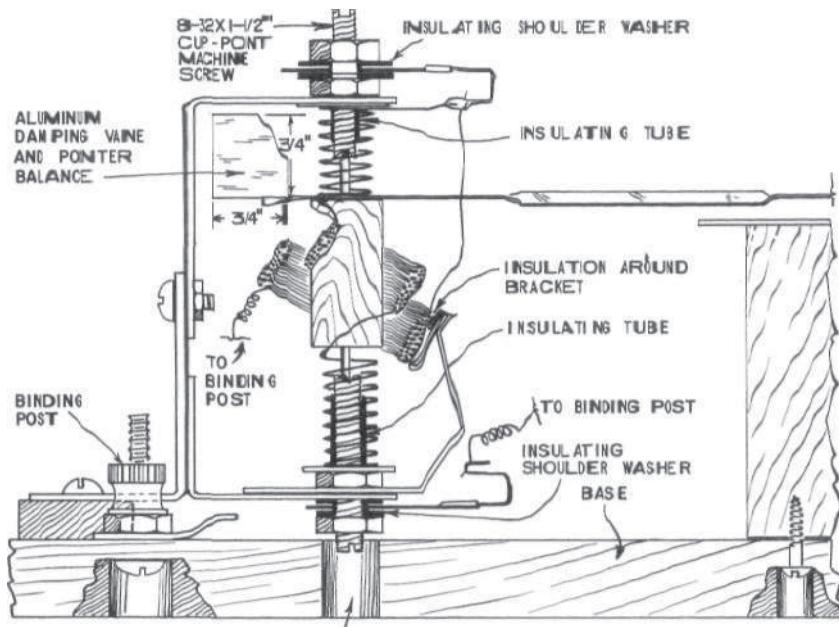


Fig. 1014. Assembly of the electrodynamometer. Make sure the dowel can turn freely. This meter, like all the others, depends on careful adjustment. Put a single drop of lubricating oil in the bearings after you have made all your adjustments.

an electric current is sent through the instrument, then the terminal wires from one of the coils will have to be reversed. This can be done easily by unsoldering the leads of the larger coil from the binding post and the top insulated lug and reversing them (be careful not to disturb the leads from the smaller coil). Note that when the needle or pointer of the dynamometer is at full-scale deflection (farthest to the right of the scale), the axes of the two coils are parallel.

Mount a 1 3/4-inch high wooden base for a scale 2 x 4 inches. Cut two small brads and insert one on either end of the scale as needle stops.

Mount the whole instrument on a 14-inch thick block of pressed board, thus providing mechanical clearance under the bottom L-bracket. Bore through the base to provide access to the bottom machine screw for vertical adjustment of the movement. This ends the building procedure for the meter. However, an aluminum counterweight or damper may be cemented to the rear end of the pointer to provide a measure of dynamic balancing to the movement.

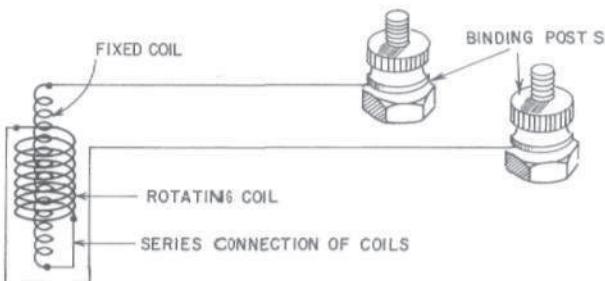


Fig. 1015. This drawing shows how the two coils are connected to each other and to the binding posts.

The d'Arsonval meter

Almost any electrical measuring instrument for use today on moderate voltages may be said to belong to the d'Arsonval family. Although essentially for use on direct currents, such as dry-cell measurements, they may be fitted for use on any type of current through the application of rectifiers, thermocouples or vacuum tubes.

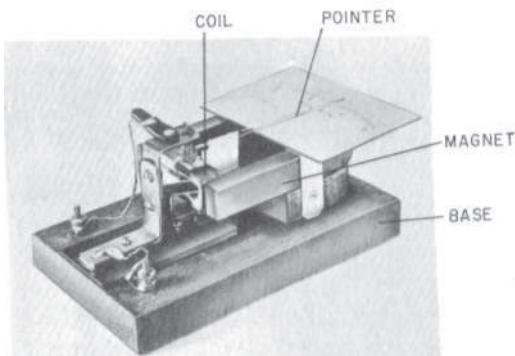


Fig. 1016. This photo shows the d'Arsonval meter we are going to build.

Ideally, d'Arsonval types consist of a rectangular coil moving in a circular air gap between the poles of a permanent magnet. The electric meter we propose to build will approximate this ideal, since it would be difficult to construct semicircular soft-iron pole pieces and fit them between the straight ends of our U-shaped magnet (which is the only magnet easily obtained in surplus stores).

The principle of operation, however, will be exactly the same. Our d'Arsonval movement is shown in Fig. 1016.

Let us now build a working model of this electrical measuring instrument with the care and consideration it deserves, for no

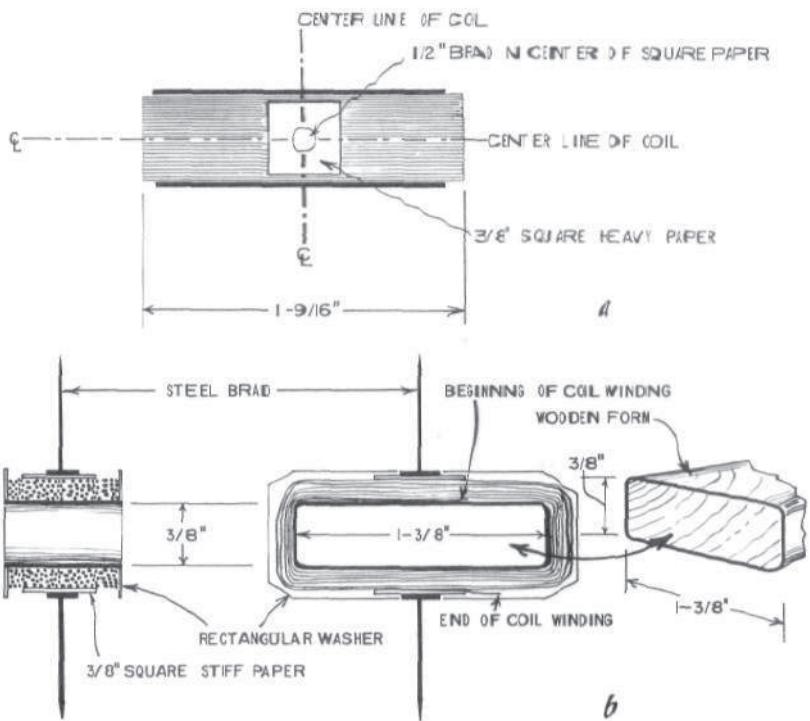


Fig. 1017. Top view (a) and side views of the coil (b).

more important piece of equipment is to be found in laboratories the world over.

Building procedure

Prepare a 4 x 7-inch base, varnish and fit with binding posts. The length and width of the base and other parts will, of course, be dictated by the size and shape of the permanent U-magnet secured. In general, the base should be at least 1-inch wider and about $2\frac{1}{2}$ inches longer than the magnet, which, in our case, is exactly 4 inches long and $1\frac{3}{4}$ inches between the ends of the poles.

Secure about 500 feet ($\frac{1}{2}$ lb. will do) of No. 37 or No. 38 enameled copper wire for the rotating coil. Wind nearly all of it on a $1\frac{3}{8}$ -inch-long and $\frac{3}{8}$ -inch-wide bobbin, formed by several turns of paper wound around the wood. Fit rectangular fiber washers over the paper to hold the wire in place as the turns go on the bobbin. Cement the washers to the paper turns, but not to the wooden form, which must be slid out of the opening in the coil when it is finished. The result should be a light coil of wire, held in place by the paper turns, the washers and cement —

the latter being applied as the winding progresses — with the beginning of the winding on one side and the end on the other (Fig. 1017).

When the coil is finished, be sure that at least 3 inches of wire are left on each side of the coil winding to serve as pigtails.

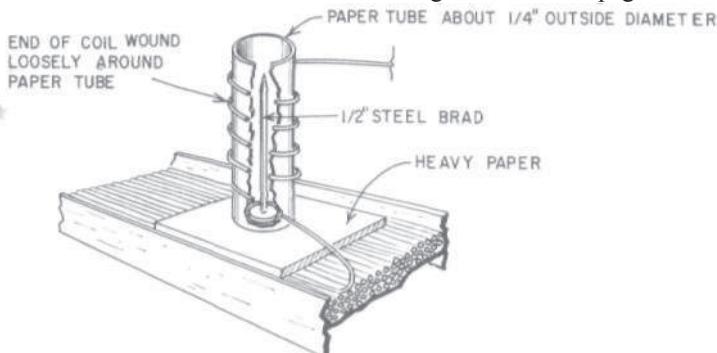


Fig. 1018. A paper tube is placed over the steel brad. Two such tubes will be needed, one for the top, the other for the bottom of the coil.

tors. Clean off about $\frac{1}{2}$ inch of the enameled coating from each pigtail, using a caustic compound. Be sure the winding and bobbin are no longer than 1-9/16 inches from end to end to permit free rotation of the coil inside the ends of the magnet's poles without rubbing.

Cement a $3/8$ -inch square of heavy paper directly over the wire on each side of the coil. These squares should be in the coil's exact center. Cement a $\frac{1}{2}$ -inch brad in the exact center of each paper square and allow this assembly to dry thoroughly.

Roll a piece of paper so it makes a tube of about $\frac{1}{4}$ inch OD with a hole inside large enough to just slip over the brad. Wind the 3-inch enameled pigtail wire loosely over this tube, with the turns close together (Fig. 1018). Then, gently draw out the paper tube, leaving a coil of wire around the brad but not touching it. This will be the coil-restoring spring of the rotating or movable armature. Follow the same procedure on the other side of the armature. The ends of the coil-restoring spring thus created are the electrical terminals of the armature and later will be connected to binding posts.

Prepare an L-bracket mount in the usual way, with a span of $1\frac{3}{4}$ inches between the two arms. Install 8-32 cup-point set screws to serve as bearings for the two 14-inch steel-brad pivots. The bracket should be screwed to the base through a piece of pressed board $1/8 \times 1\frac{1}{2} \times 3$ inches.

Prepare an iron core $\frac{1}{4} \times 1$ inch and screw it to a brass supporting bracket, which in turn should be bolted to the L-bracket mount (Fig. 101 9). (This is an exacting job. The slug must not touch the coil, and the coil must not touch any part of the U-magnet. A few moments of painstaking effort, however, will solve the problem.)

Attach the U-magnet to the base by securing it to a $\frac{3}{4}$ -inch-thick block of wood. Thereafter, bolt or screw the wooden block to the base through a hole bored through the block's center. This will make it possible to adjust the magnet with relation to the rotating coil to prevent touching.

One of the final things to do is to cut a 4-inch sliver of sheet aluminum, fashion it into a pointer, and fix it to the rotating coil

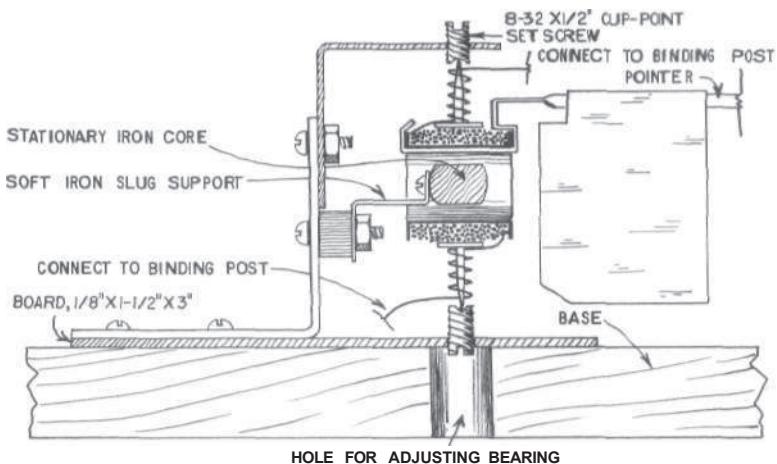


Fig. 1019. An iron slug is mounted inside the coil but does not touch it. The coil must be free to turn and the slug must not interfere with the motion of the coil. There are no electrical connections to the slug. It is mounted by means of a support, as shown.

with cement. If the cement is applied liberally and allowed to dry thoroughly before handling the pointer will be firmly fixed to the coil bobbin.

The last thing to do with the d'Arsonval-movement meter is to draw a scale and cement it to the top of the U-magnet. Then connect the terminal lugs to the two binding posts.

Note: To check the calibration, connect the d'Arsonval meter to the terminals of a dry cell which, when fresh, will furnish about 1.5 volts and swing the needle to the extreme right or left of the calibrated scale. If it does not check, draw a new calibration chart,

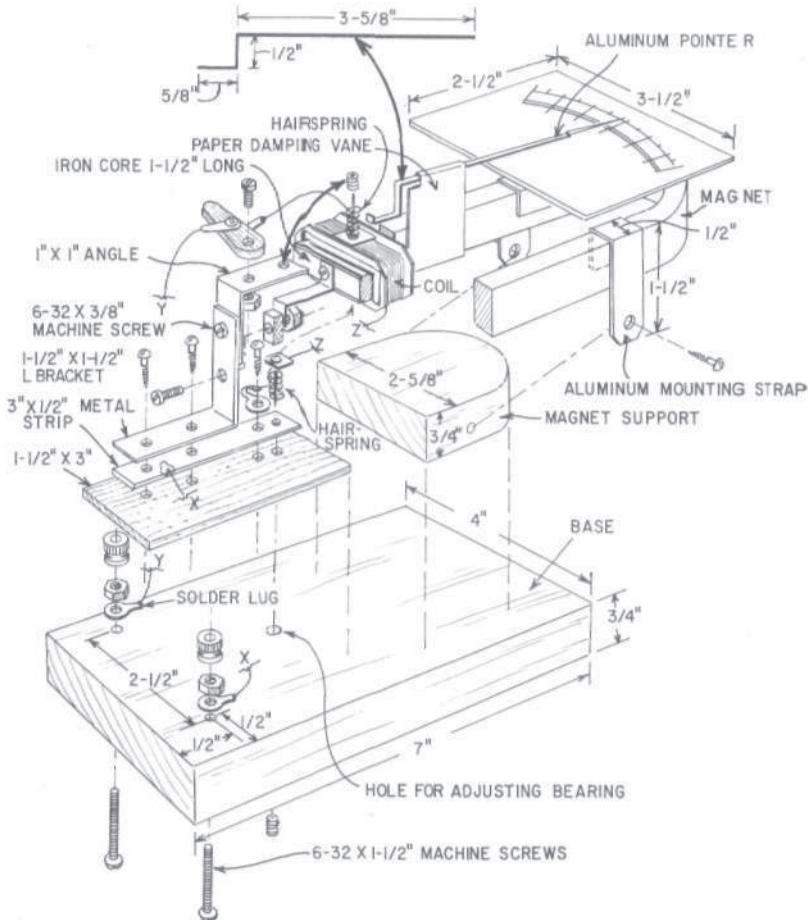


Fig. 1020. Exploded view of the d'Arsonval meter.

parts list for the d'Arsonval meter

Wire: $\frac{1}{2}$ lb. No. 37 or No. 38 enameled copper.

Magnet: U type.

Hardware: 2—6-32 x $1\frac{1}{2}$ inch machine screws; 1—6-32 x 3/8 machine screws; 4—6-32 x $\frac{3}{4}$ inch wood screws; 1—6-32 x $\frac{1}{2}$ inch brass wood screw; 2—8-32 x $\frac{1}{2}$ inch Parker-Kalon set screws; 2—soldering lugs; 3—6-32 hex nuts; 2—6-32 knurled nuts; 2—steel brads, $\frac{1}{2}$ inch; 1—

$1\frac{1}{2} \times 1\frac{1}{2}$ inch L bracket; 1—1 x 1 inch L bracket.

Miscellaneous: wood base, 4 x 7 x $\frac{3}{4}$ inches; wood block, $2\frac{1}{2} \times VA$ inches; pressed board (or wooden board) $1\frac{1}{8} \times 1\frac{1}{2} \times 3$ inches; wood bobbin, $1\frac{3}{8} \times 3\frac{3}{8}$ inches; iron core, 1 x VA inch; cardboard scale, $2\frac{1}{2} \times 3\frac{1}{2}$ inches; aluminum strip for pointer, 4 x VA inches; 2—aluminum mounting straps, $2\frac{1}{2} \times \frac{1}{2}$ inches; aluminum strip, $3 \times \frac{1}{2}$ inches.

marking the 1.5-volt position of the painter on either side of the zero center mark.

Of course, the needle should be adjusted to the center of the scale by moving the top insulated lag back and forth- that is, to the right or the left. The new calibration may be cemented over the old one and the needle bent slightly upward to clear the scale,

An exploded view of the d'Arsonval meter is shown in fig. 1020. Make sure the coil is centered between the ends of the permanent magnet.

Experiments to try

Experiment 1

Obtain a fresh $1\frac{1}{2}$ volt No. 6 dry cell and connect it to the binding posts of the moving-iron meter. Note the distance the pointer swings.

Now transpose the leads to the dry cell. Observe that the pointer moves exactly the same distance and in the same direction. This means that with this type of instrument we do not need to be careful of the polarity of the voltage source we are measuring.

Experiment 2

Disconnect one of the leads between the moving-iron meter and the dry cell. Connect a 6-inch length of copper wire to the binding post on the meter (the other binding post is still connected to the dry cell). Also connect a 6-inch length of copper wire to the free terminal of the dry cell.

Touch the two wires. The meter pointer will swing to the right. Now touch the two wires to various materials such as paper, cloth, glass, etc. Also try metals such as silver (a silver spoon will do), a hairpin, a safety pin and other items found in the home. Materials can be classified as conductors and insulators. Those materials that produce a swing of the pointer are conductors. Those that do not, are insulators.

Experiment 3

Connect one terminal of a $1\frac{1}{2}$ volt dry cell to one binding post of the electrodynamometer. Attach a wire to the other binding post. Tap the exposed end of this wire to the other terminal of the dry cell. If the meter pointer moves to the right, you can make the connection safely. If the pointer swings to the left, transpose both wires and the meter will work properly. Always be careful when making battery connections to electrodynamometer and d'Arsonval meters.

Experiment 4

Connect a $1\frac{1}{2}$ volt dry cell to the electrodynamometer. Note

the distance the pointer moves. Put another dry cell in series with the first cell. The meter pointer should now move twice as far along the scale.

Experiment 5

Fill a glass with water and add a teaspoonful of table salt. Stir until the salt is completely dissolved. Connect one 6-inch length of bare copper wire to the binding post of the electrodynamometer. Connect another 6-inch length of bare copper wire to one terminal of a $4\frac{1}{2}$ volt dry cell. Insert the free ends of the two wires in the salt water. Connect the other binding post on the meter to the unused terminal of the dry cell. Note the effect of the salt water on the distance the meter pointer moves.

Experiment 6

Repeat experiment 5 but move the wires in the salt water closer to and then away from each other. Observe the effect this has on the movement of the meter pointer.

Experiment 7

Replace the salt water with fresh water. What effect does this have on the movement of the pointer?

Experiment 8

Repeat experiments 2 to 6 using the d'Arsonval meter.

